L Number	Hits	Search Text	DB	Time stamp
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-	673	(370/320,335,342,441,479.ccls. 375/130,140,141,145.ccls.) and CDMA and (PN adj code$1) and (base adj station)	USPAT; US-PGPUB	2004/03/08 15:25
-	63	((370/320,335,342,441,479.ccls. 375/130,140,141,145.ccls.) and CDMA and (PN adj code$1) and (base adj station)) and ((idle or busy or occup$3) near signal$4)	USPAT; US-PGPUB	2004/03/08 15:56
-	1503	370/450,459.ccls. 455/450,452.1.ccls.	USPAT; US-PGPUB	2004/03/08 15:56
-	36	(370/450,459.ccls. 455/450,452.1.ccls.) and (CDMA) and (PN adj code$1) and (base adj station)	USPAT; US-PGPUB	2004/03/08 16:12
-	813	(CDMA) and (PN adj code$1) and (base adj station) not (370/320,335,342,441,479.ccls. 375/130,140,141,145.ccls.) not (370/450,459.ccls. 455/450,452.1.ccls.)	USPAT; US-PGPUB	2004/03/08 16:12
-	7	((CDMA) and (PN adj code$1) and (base adj station) not (370/320,335,342,441,479.ccls. 375/130,140,141,145.ccls.) not (370/450,459.ccls. 455/450,452.1.ccls.)) and ((control and idle) near channel)	USPAT; US-PGPUB	2004/03/09 14:34
-	10	(base adj station) near (PN adj codes)	USPAT; US-PGPUB	2004/03/09 09:52
-	45	(dynamic$4 near allocat$3 near channel$1) and CDMA	USPAT; US-PGPUB	2004/03/09 10:05
-	39	(borrow$3 near channel$1) and CDMA	USPAT; US-PGPUB	2004/03/09 10:17
-	1	5722043.pn.	USPAT; US-PGPUB	2004/03/09 10:18
-	89	(dynamic$4 near channel near assign$5) and CDMA	USPAT; US-PGPUB	2004/03/09 10:19
-	67	((dynamic$4 near channel near assign$5) and CDMA) not ((base adj station) near (PN adj codes)) not ((dynamic$4 near allocat$3 near channel$1) and CDMA) not ((borrow$3 near channel$1) and CDMA)	USPAT; US-PGPUB	2004/03/09 10:28
-	1453	cdma and ((signal$4 and (traffic or bearer)) near channel$1)	USPAT; US-PGPUB	2004/03/09 12:08
-	1412	cdma and ((signal$4 and traffic) near channel$1)	USPAT; US-PGPUB	2004/03/09 12:08
-	48	(cdma and ((signal$4 and traffic) near channel$1)) and (dynamic$4 near channel)	USPAT; US-PGPUB	2004/03/09 12:09

US005669062A

United States Patent [19]

Olds et al.

[11] Patent Number: 5,669,062

[45] Date of Patent: Sep. 16, 1997

[54] METHODS OF DEMAND-BASED ADAPTIVE CHANNEL REUSE FOR TELECOMMUNICATIONS SYSTEMS

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[73] Assignee: Motorola, Inc., Schaumburg, Ill.

[21] Appl. No.: 709,927

[22] Filed: Sep. 9, 1996

Related U.S. Application Data

[63] Continuation of Ser. No. 329,926, Oct. 27, 1994, abandoned.

[51] Int. Cl.[6] H04B 7/26; H04B 7/185; H04Q 7/36

[52] U.S. Cl. 455/509; 455/12.1; 455/62; 455/63

[58] Field of Search 455/12.1, 13.1, 455/33.1–33.4, 34.1, 34.2, 52.2, 52.3, 54.1, 54.5, 62, 63; 379/59, 60

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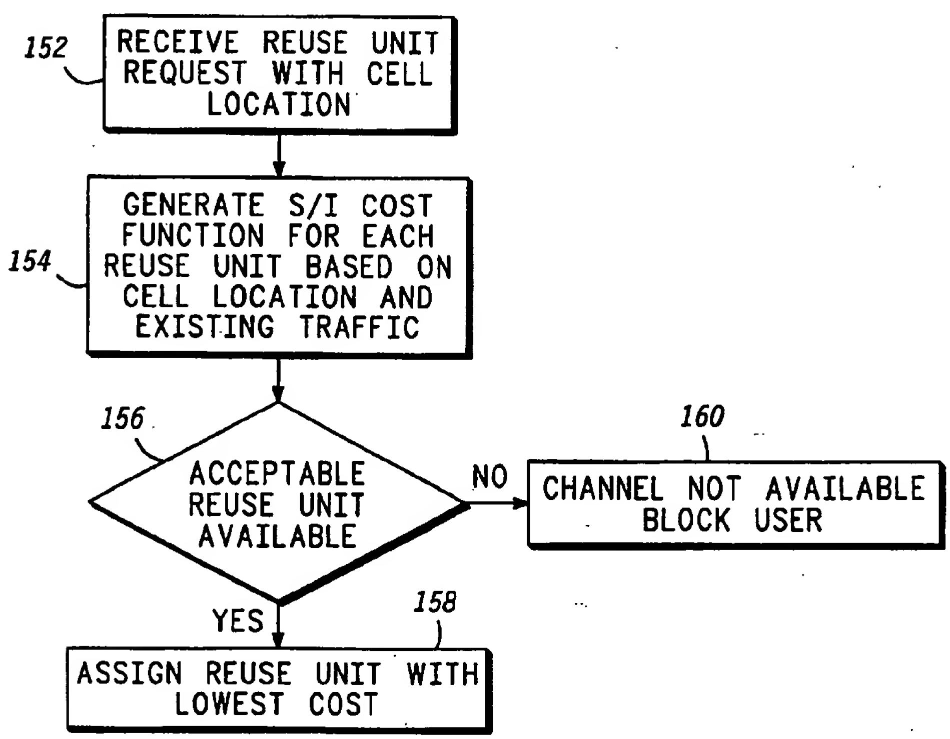
Primary Examiner—Chi H. Pham
Attorney, Agent, or Firm—Harold C. McGurk

[57] ABSTRACT

Methods efficiently assign user channels in a LEO (low-earth orbit) telecommunication system. These methods adapt the channel reuses based on system load or demand. These methods achieve high capacity and minimize interference for the particular situation. Since these methods are adaptive, they adjust to maintain efficient operation as the load conditions change.

16 Claims, 5 Drawing Sheets



150

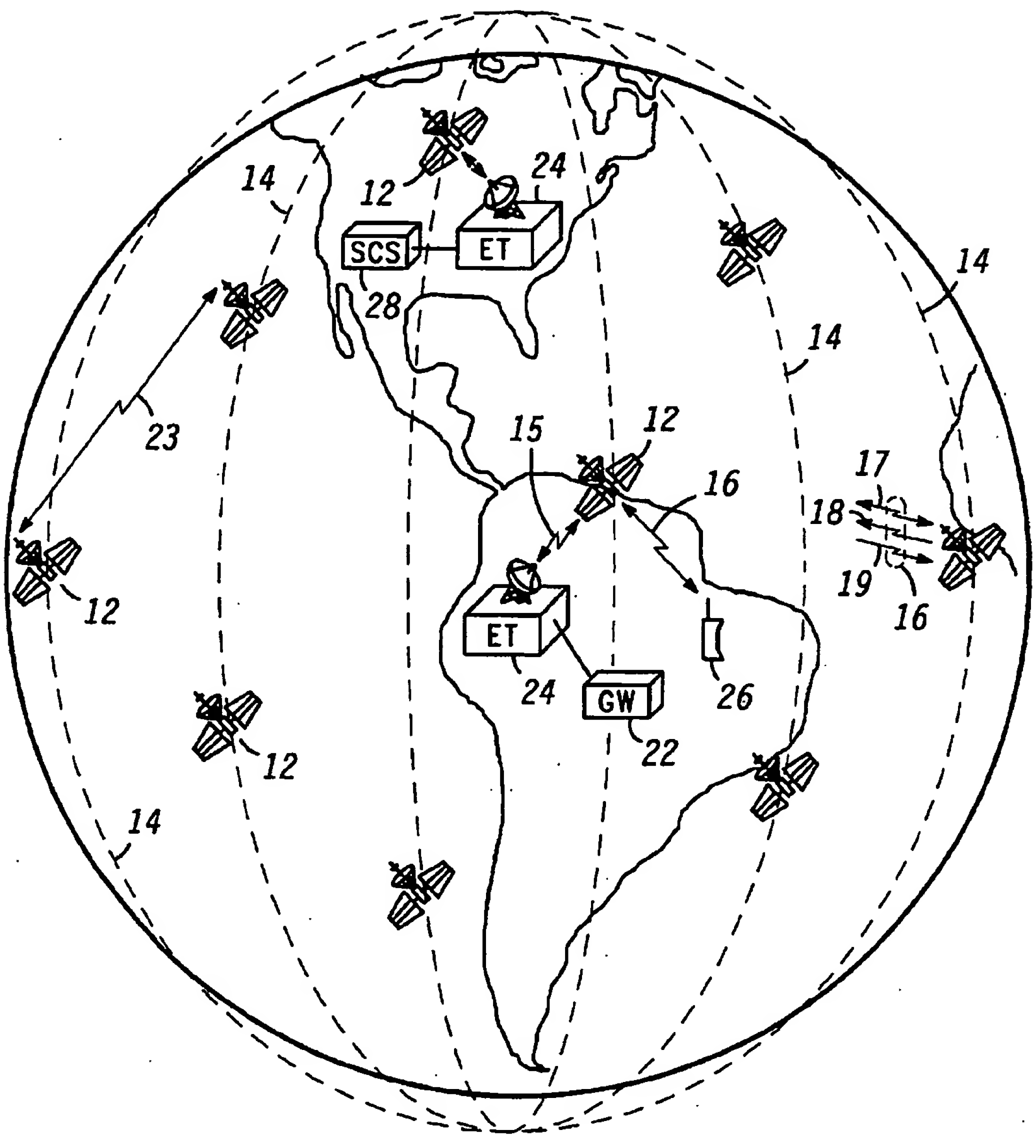

14
12
24
SCS
ET
28
14
14
23
15
12
16
17
18
19
16
12
ET
24
GW
22
26
12
14
12
10

FIG. 1

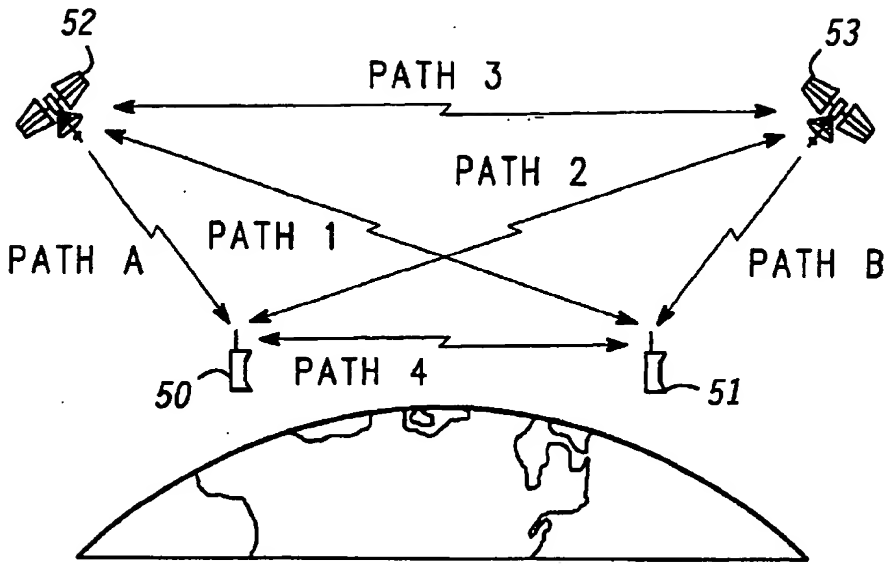

52
53
PATH 3
PATH 2
PATH A
PATH 1
PATH B
PATH 4
50
51

FIG. 2

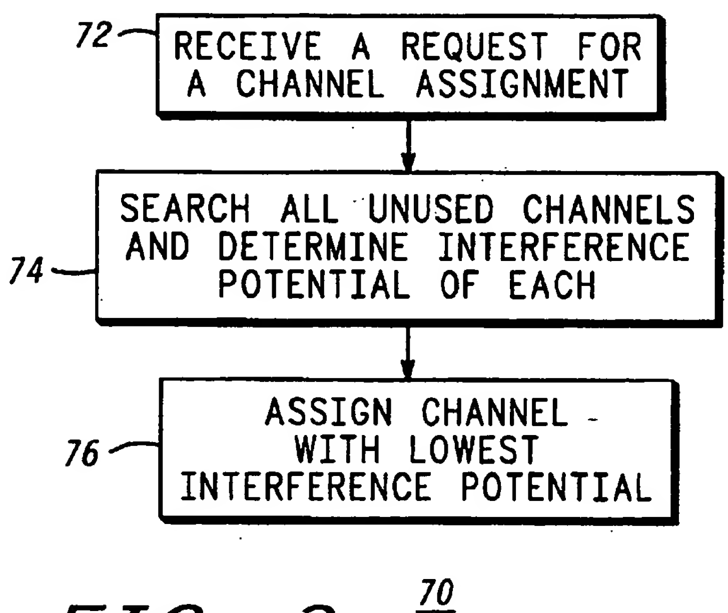

72
RECEIVE A REQUEST FOR A CHANNEL ASSIGNMENT
74
SEARCH ALL UNUSED CHANNELS AND DETERMINE INTERFERENCE POTENTIAL OF EACH
76
ASSIGN CHANNEL WITH LOWEST INTERFERENCE POTENTIAL
70

FIG. 3

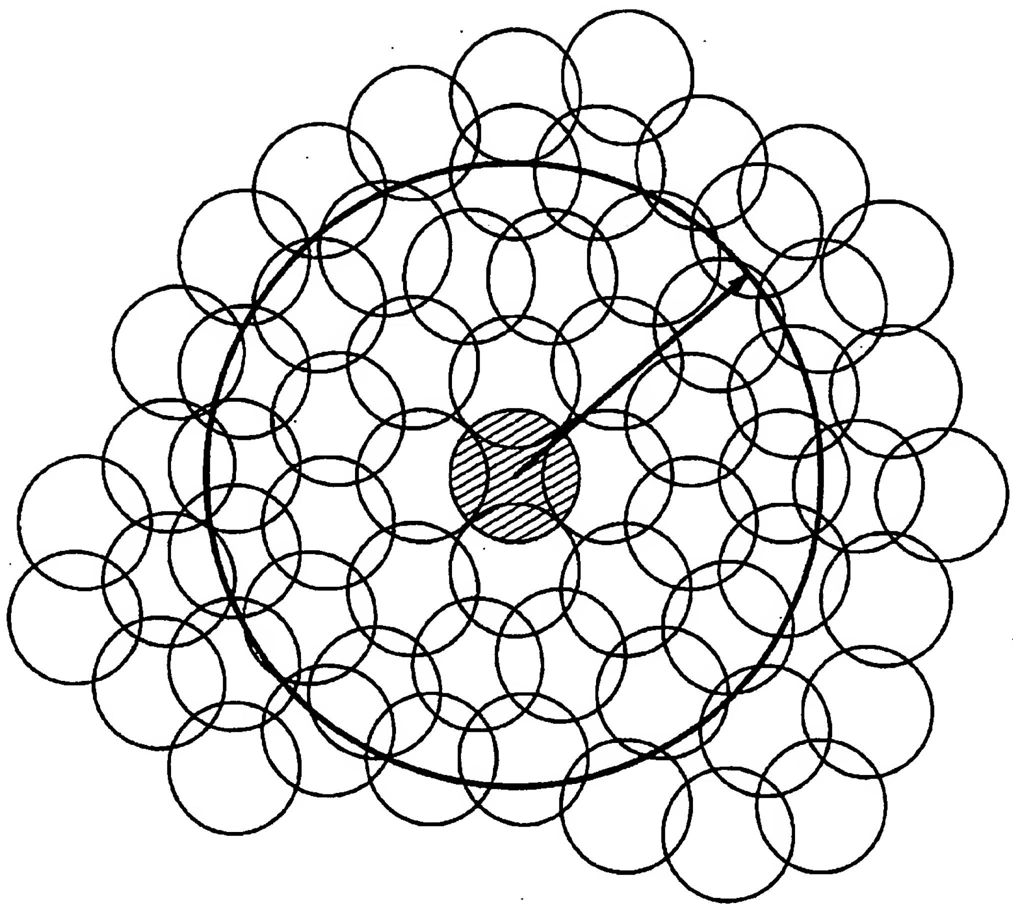
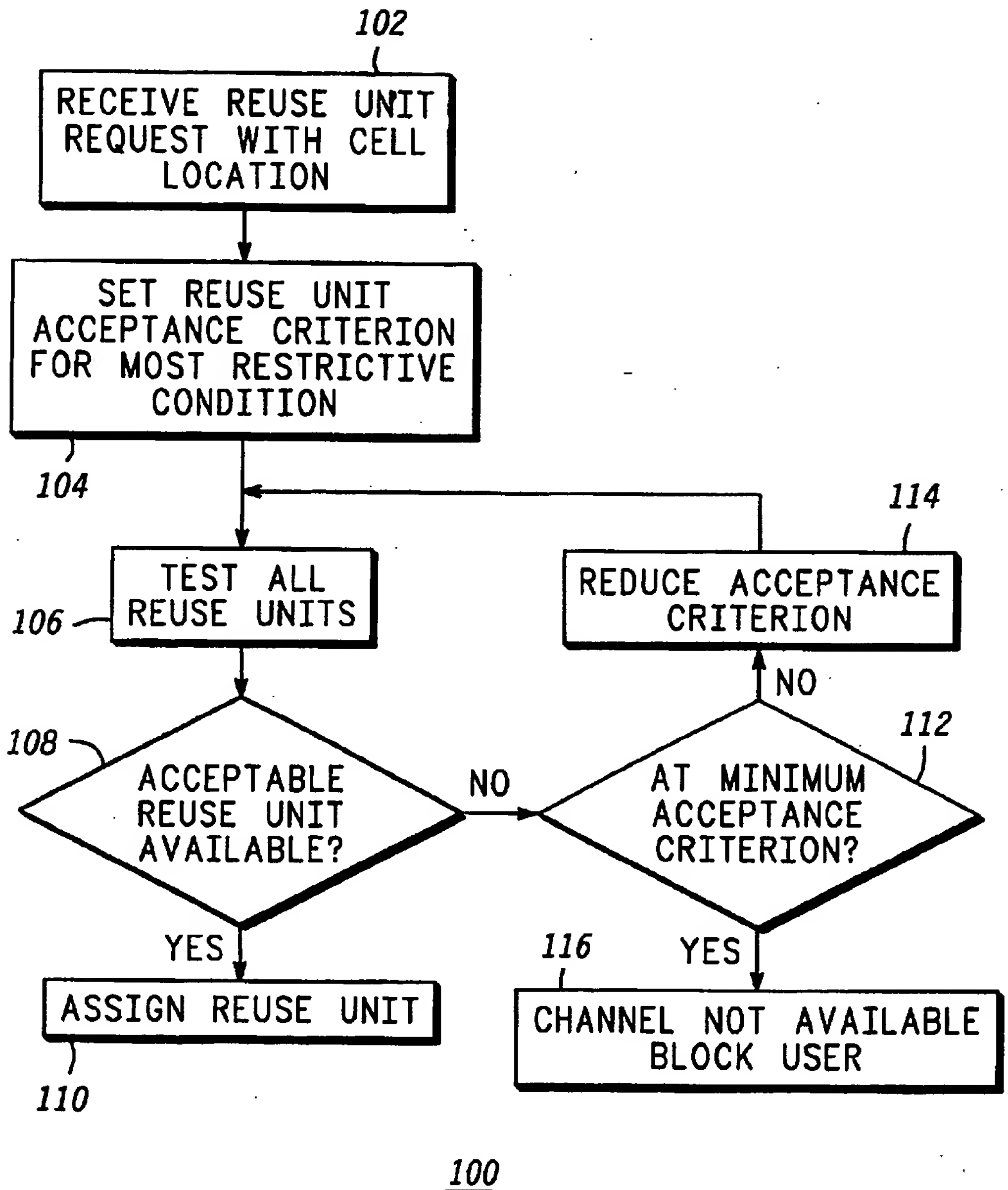


FIG. 4



102
RECEIVE REUSE UNIT REQUEST WITH CELL LOCATION
SET REUSE UNIT ACCEPTANCE CRITERION FOR MOST RESTRICTIVE CONDITION
104
114
TEST ALL REUSE UNITS
106
REDUCE ACCEPTANCE CRITERION
NO
108
ACCEPTABLE REUSE UNIT AVAILABLE?
NO
AT MINIMUM ACCEPTANCE CRITERION?
112
YES
116
YES
ASSIGN REUSE UNIT
CHANNEL NOT AVAILABLE BLOCK USER
110
100

FIG. 5

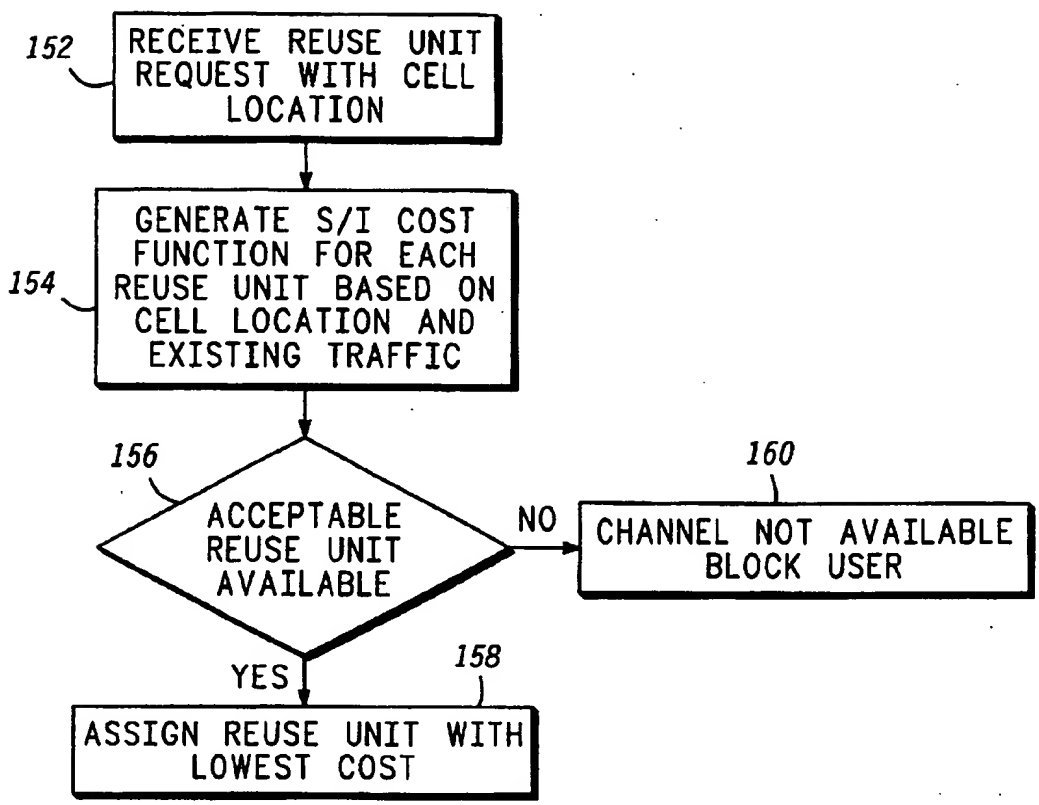

152
RECEIVE REUSE UNIT REQUEST WITH CELL LOCATION
154
GENERATE S/I COST FUNCTION FOR EACH REUSE UNIT BASED ON CELL LOCATION AND EXISTING TRAFFIC
156
ACCEPTABLE REUSE UNIT AVAILABLE
NO
160
CHANNEL NOT AVAILABLE BLOCK USER
YES
158
ASSIGN REUSE UNIT WITH LOWEST COST

FIG. 6 150

METHODS OF DEMAND-BASED ADAPTIVE CHANNEL REUSE FOR TELECOMMUNICATIONS SYSTEMS

This application is a continuation of prior application Ser. No. 08/329,926, filed Oct. 27, 1994 now abandoned.

TECHNICAL FIELD

This invention relates generally to telecommunication systems and, in particular, to methods for managing and reusing channels in a telecommun-ication system based on interference potential.

BACKGROUND OF THE INVENTION

In terrestrial-based cellular systems, channel assignments are made within fixed frequency reuse cell clusters. A cluster comprises a set of predetermined cells which are adjacent to each other. That is, each cell within a predetermined cluster is given a unique set of orthogonal channels so that channels within a cluster do not interfere with one another. Outside of the cluster, the channels are reused. The reuse between clusters follows a fixed pattern designed to minimize interference between the clusters.

The reuse cluster technique associated with terrestrial-based cellular systems is difficult to implement when the cellular base stations are replaced by satellites in a low-earth orbit (LEO). Time division multiplex access (TDMA) and frequency division multiple access (FDMA) communication systems and systems that use similar channel structures avoid excessive interference by assigning traffic channels that do not conflict with other traffic channels in time or frequency. The channel assignment problem is exacerbated when one end of the communication system is located at the LEO satellites where differential Doppler shifts and differential propagation times can cause transmissions between a user and a satellite to interfere with channels on another satellite. This problem becomes even more severe when earth terminals or stations can transmit and receive over large coverage angles that may include several satellites.

Accordingly, there is a significant need for methods which efficiently use the available frequency spectrum without interfering with other channels.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention is pointed out with particularity in the appended claims. However, other features of the invention will become more apparent and the invention will be best understood by referring to the following detailed description in conjunction with the accompanying drawings in which:

FIG. 1 depicts a highly simplified diagram of a satellite-based telecommunication system of which the present invention may form a portion thereof;

FIG. 2 depicts a satellite interference scenario;

FIG. 3 shows a method for matching the managing and reusing channels in accordance with a preferred embodiment of the present invention;

FIG. 4 depicts a cellular telecommunication system cell map and a shaded cell requiring more capacity;

FIG. 5 shows a maximum distance method for reusing channels in accordance with a preferred embodiment of the present invention; and

FIG. 6 shows a minimum interference cost method for reusing channels in accordance with a preferred embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention involves methods for managing and reusing channels based on adaptive rules. The methods may predict the reuse channels or may operate in real-time. The adaptive rules help to determine the highest capacity at the lowest interference that is possible for a particular user demand situation. The basic concept is to match the reuse factor to the actual demand at a particular time and place. In accordance with a preferred embodiment, a user accesses the system and requests a channel assignment. Next, the system searches through all unused channels and checks the interference potential of each available channel against all channels that are already assigned. Finally, the system assigns the channel with the lowest interference potential.

A "satellite" means a man-made object or vehicle intended to orbit a celestial body such as the earth. The term "satellite" is intended to include both geostationary and orbiting satellites and/or combinations thereof including low-earth orbiting (LEO) satellites. The word "earth" is intended to include any celestial body around which a communication satellite may orbit. A "constellation" means an ensemble of satellites arranged in orbits for providing specified coverage (e.g., radio communication, photogrammetry, etc.) of portion(s) or all of the celestial body. A constellation typically includes multiple rings (or planes) of satellites and may have equal numbers of satellites in each plane, although this is not essential. The terms "cell" and "antenna pattern" are not intended to be limited to any particular mode of generation and include those created by either terrestrial or satellite cellular telecommunication systems and/or combinations thereof.

FIG. 1 illustrates a highly simplified diagram of satellite-based telecommunication system 10, dispersed over and surrounding earth through use of orbiting satellites 12 occupying orbits 14. The present invention is applicable to telecommunication systems including satellites having low-earth and medium-earth orbits. Additionally, it is applicable to orbits having any angle of inclination (e.g., polar, equatorial or another orbital pattern).

Communication system 10 uses six polar orbits 14, with each orbit 14 having eleven satellites 12 for a total of sixty-six satellites 12. Although this is preferred, it is not essential because more or fewer satellites, or more or fewer orbits, may be used. While the present invention is advantageously employed when a large number of satellites are being used, it is also applicable with as few as a single satellite. For clarity, FIG. 1 illustrates only a few of satellites 12 of the constellation.

For example, each orbit 14 encircles earth at an altitude of around 785 km, although higher or lower orbital altitudes may be usefully employed. Due to the relatively low orbits of satellites 12, substantially line-of-sight electromagnetic (e.g., radio, light etc.) transmission from any one satellite 12 or reception of signals by any one satellite 12 covers a relatively small area of earth at any instant. For the example shown, satellites 12 travel with respect to earth at around 25,000 km/hr, allowing satellite 12 to be visible to a terrestrial station or ISUs 26 for a period of approximately nine minutes.

Satellites 12 communicate with terrestrial stations which may include some number of radio communication individual subscriber units (ISUs) 26 and earth terminals (ETs) 24 connected to system control segment (SCS) 28. ETs 24 may also be connected to gateways (GWs) 22 which provide access to a public switched telephone network (PSTN) or

other communications facilities. Only one each of GWs 22, SCSs 28 and ISUs 26 are shown in FIG. 1 for clarity and ease of understanding. ETs 24 may be co-located with or separate from SCS 28 or GW 22. ETs 24 associated with SCSs 28 receive data describing status of satellites 12 and GWs 22 and relay packets of control information. ETs 24 associated with GWs 22 primarily receive and relay packets relating to calls in progress from/to ISUs 26 and satellites 12.

ISUs 26 may be located anywhere on the surface of the earth or in the atmosphere above the earth. ISUs 26 are preferably communications devices capable of transmitting data to and receiving data from satellites 12. By way of example, ISUs 26 may be hand-held, portable cellular telephones adapted to communicate with satellites 12. Ordinarily, ISUs 26 need not perform any control functions for communication system 10.

Communication system 10 may accommodate any number, potentially in the millions, of ISUs 26. In the preferred embodiments of the present invention, ISUs 26 communicate with nearby satellites 12 via subscriber links 16. Links 16 encompass a limited portion of the electromagnetic spectrum that is divided into numerous channels. Links 16 are preferably combinations of L-Band and/or K-Band frequency channels and may encompass Frequency Division Multiple Access (FDMA) and/or Time Division Multiple Access (TDMA) and/or Code Division Multiple Access (CDMA) communications or combinations thereof. At a minimum, satellite 12 regularly transmits over one or more broadcast channels 18. ISUs 26 synchronize to broadcast channels 18 and monitor broadcast channels 18 to detect data messages which may be addressed to them. ISUs 26 may transmit messages to satellites 12 over one or more acquisition channels 19. Broadcast channels 18 and acquisition channels 19 are not dedicated to any one ISU 26 but are shared by all ISUs 26 currently within view of a satellite 12.

On the other hand, traffic channels 17 are two-way channels that are assigned to particular ISUs 26 by satellites 12 from time to time. In the preferred embodiments of the present invention, a digital format is used to communicate data over channels 17–19, and traffic channels 17 support real-time communications. At least one traffic channel 17 is assigned for each call, and each traffic channel 17 has sufficient bandwidth to support, at a minimum, a two-way voice conversation. To support real-time communications, a time division multiple access (TDMA) scheme is desirably used to divide time into frames, preferably in the 10–90 millisecond range. Particular traffic channels 17 are assigned particular transmit and receive time-slots, preferably having durations in the 3–10 millisecond range, within each frame. Analog audio signals are digitized so that an entire frame's signal is transmitted or received in a single short high speed burst during an allotted time-slot. Preferably, each satellite 12 supports up to a thousand or more traffic channels 17 so that each satellite 12 can simultaneously service a number of independent calls. Those skilled in the art, however, will recognize that traffic channels can be formed without this time slot structure and that methods that do not require digitizing the analog voice signal may be employed. The precise method used to form the channels and process the voice communication is not important to this invention.

Satellites 12 communicate with other nearby satellites 12 through cross-links 23. Thus, a call or communication from an ISU 26 located at any point on or near the surface of the earth may be routed through the constellation of satellites 12 to within range of substantially any other point on the surface of the earth. A communication may be routed down to an ISU 26 on or near the surface of the earth from a satellite 12 using subscriber link 16. Alternatively, a communication may be routed down to or up from any of many ETs 24, of which FIG. 1 shows only two, through earth links 15. ETs 24 are usually distributed over the surface of the earth in accordance with geo-political boundaries. In the preferred embodiments, each satellite 12 may communicate with up to four ETs 24 and over a thousand ISUs 26 at any given instant.

SCS 28 monitors the health and status of system communication nodes (e.g., GWs 22, ETs 24 and satellites 12) and desirably manages operations of communication system 10. One or more ETs 24 provide the primary communications interface between SCS 28 and satellites 12. ETs 24 include antennas and RF transceivers and preferably perform telemetry, tracking and control functions for the constellation of satellites 12.

GWs 22 may perform call processing functions in conjunction with satellites 12 or GWs 22 may exclusively handle call processing and allocation of call handling capacity within communication system 10. Diverse terrestrial-based communication systems, such as the PSTN, may access communication system 10 through GWs 22.

With the example constellation of sixty-six satellites 12, at least one of satellites 12 is within view of each point on the earth's surface at all times, resulting in full coverage of the earth's surface. Any satellite 12 may be in direct or indirect data communication with any ISU 26 or ET 24 at any time by routing data through the constellation of satellites 12. Accordingly, communication system 10 may establish a communication path for relaying data through the constellation of satellites 12 between any two ISUs 26, between SCS 28 and GW 22, between any two GWs 22 or between ISU 26 and GW 22.

The present invention is also applicable to satellite constellations where full coverage of the earth is not achieved (i.e., where there are "holes" in the communications coverage provided by the constellation) and constellations where plural coverage of portions of the earth occur (i.e., more than one satellite is in view of a point on the earth's surface).

In general terms, communication system 10 may be viewed as a network of nodes. Each satellite 12, GW 22, and ISU 26 represents a node of communication system 10. All nodes of communication system 10 are or may be in data communication with other nodes of communication system 10 through communication links 15, 16, and/or 23. In addition, all nodes of communication system 10 are or may be in data communication with other telephonic devices dispersed throughout the world through PSTNs and/or conventional terrestrial cellular telephone devices coupled to the PSTN through conventional terrestrial base stations.

FIG. 2 illustrates potential interference paths that can occur in a satellite telecommunication system. Paths A and B are the desired signal paths between subscriber units 50 and 51 and satellites 52 and 53, respectively. In this example, subscriber unit 50 and satellite 52 are synchronized so that transmissions from subscriber unit 50 arrive at satellite 52 during the correct receiver window for the assigned channel and visa versa. Satellite 53 is at a different distance from subscriber unit 50 than satellite 52 and is moving at a different velocity relative to subscriber unit 50 than satellite 52.

There is generally a different propagation delay and Doppler frequency shift between satellite 53 and subscriber unit 50 than there is between satellite 52 and subscriber unit

50. Any interference that reaches satellite 53 from subscriber unit 50 may not be in the time slot and frequency access that corresponds to the user channel of subscriber unit 50. The interference may have "slid" into a different channel. If this second channel has been assigned to subscriber unit 51, unacceptable interference will result. Thus, even if channels are only used once, channels from one station may interfere with channels from a different station in a dynamic system.

The method of the preferred embodiment of the invention is to match the reuse factor to the actual demand at a particular time and place. FIG. 3 shows a channel management and reuse method 70 in accordance with a preferred embodiment of the present invention. Channel management and reuse method 70 is preferred executed by a computer on-board the satellite or by the SCS. As shown in FIG. 3, a user (e.g., a subscriber unit or an earth terminal) accesses the system and requests in step 72 an assignment of a channel. Next, method 70 searches in step 74 through all unused channels and checks the interference potential of each available channel against all channels that are already assigned. Method 70 then assigns in step 76 the channel with the lowest interference potential.

There are several variations on the fundamental method. For example, the search can be terminated as soon as a channel is found that meets minimum interference criterion, instead of searching all channels and taking the channel with the lowest interference. As an example, if the number of active users were low in a particular geographical area, the minimum interference criterion would be satisfied if the channels which are able to produce interference are used over the radio horizon. In this case, referring to FIG. 2, paths 1 and 2 would not exist because the surface of the earth would prevent electromagnetic energy emitted from either end of the path from reaching the subscriber unit or the satellite. By prior calculation, there may exist a relationship between distance and the amount of interference anticipated. If this exists, then distance measured in the radius shown in FIG. 4, is used as a surrogate for a direct measurement or calculation of the interference.

Another modification would be to insist that the minimum interference criterion be met before any channel is assigned. If no channel meets this criterion, the user is denied access to the communication system. A further modification would be to determine an anticipated demand for a duration of a planning interval by searching through all unused channels and checking interference potential of each unused channel against all channels that are already assigned. The channel with the lowest interference potential would be allocated to the channel within which a demand is expected. Finally, the satellites, the location of the subscriber units, and the interference sources would be propagated in time to create a preplanned allocation of channels with minimum interference potential.

Assigning channels based on minimum interference potential results in adapting the amount and location of channel reuse so that it causes the minimum interference for the current demand and user distribution. This is a great advantage over fixed reuse patterns that place all reused channels at as high an interference level as the design limit allows. Fixed patterns tend to cause users to have relatively high interference even though the system is lightly loaded and excess capacity is available. In addition, since fixed reuse patterns must be based on worst case assumptions about the distribution of users that might interfere with one another, the capacity of the system is artifically limited for many actual user distributions.

The methods that implement the adaptive reuse concept basically operate by searching through the space of available channels and selecting an optimum combination of channels that service the demand with minimal interference. To accomplish this, the method predicts the interference that would result from a particular combination of channels. The method also searches the available channel space by incorporating knowledge about what factors reduce and increase interference.

There are four basic system parameters that help to predict interference between channels in a FDMA/TDMA system: sparing between channel reuses, differential time of arrival from more than one source (time slide), differential Doppler or perceived frequency of arrival (frequency slide), and antenna pattern. An adaptive reuse method restricts interference by controlling one or more of these parameters. These parameters are discussed in greater detail below.

Spacing between channel reuses involves the physical space between interfering subscriber units. If reused channels can be physically separated so that any possible subscriber receiver falls beyond the radio horizon of a potentially interfering transmitter, no interference is possible. When the interferer is brought closer to the other subscriber unit, the interference potential increases.

As explained above in the discussion of FIG. 2, when a subscriber unit is synchronized to a satellite, it may interfere with a different channel projected by the second satellite because the propagation delay from the subscriber unit to the second satellite is different from the delay between the subscriber unit and the first satellite. This differential propagation delay causes energy from the subscriber unit to "slide" into the time slot of the victim channel. This is known as a time slide.

For time slide to occur, the interfering and victim channels must use the same frequency access and be in adjacent or nearly adjacent time slots. When the time separation between the two channels is greater than the maximum propagation time difference from a subscriber unit to a satellite directly overhead and from a subscriber unit to a satellite at the horizon, interference due to lime slide is impossible.

Differential Doppler shifts between a subscriber unit and two satellites create interference in essentially the same manner as differential propagation delay. In this case, however, the interfering channel is in the same time slot as the victim channel, and the Doppler shift causes the interfering energy to slide into a nearby frequency access. When the two channels are separated in frequency by greater than twice the maximum Doppler shift between a satellite and a subscriber unit, interference due to frequency slide is not possible.

Note that a combination of time and frequency slide may cause interference between two channels that are not on either the same frequency access or in the same time slot. The time separation and frequency separation conditions from avoiding interference may apply for this combined case as well as for the pure time slide or pure frequency slide cases.

Interference between channels is only possible when energy from an interfering channel transmitter is radiated toward a victim channel receiver. LEO satellites generally use spot beam antennas to direct the uplink and downlink channels into particular areas on the earth's surface. The relative locations of channels assignments can be controlled so that the transmitter and receiver antenna patterns prevent potentially interfering channels from receiving significant power from each other.

In addition to these controllable parameters, the interference experienced by a LEO system is also a function of

environmental factors that the system cannot control. The major environmental effects comprise for example, multipath reflections and shadowing due to obstructions in the radio propagation paths. These environmental factors result in time-varying fading of the signal at a system receiver. Since different transmissions will encounter different fading levels, an interfering signal may actually have a propagation loss advantage relative to the victim signal. Environmental factors of this kind cannot be controlled by the system, but can be included in the interference prediction part of the adaptive reuse method.

In order to avoid excessive system self-interference, subscriber units or users must be continuously separated from other users operating nearby spatially and in time and/or frequency. For avoiding self-interference, it is desirable to physically separate users with the same time and frequency assignments by a large distance. To maximize system capacity, it is desirable for the same users to be as physically close together as possible. The method adaptively performs this trade-off, keeping users very far apart when system loading is light. When the demand on the system increases, the method permits assignments to be made close together, but only as dose as dictated by the demand. Finally, there is a floor on user separation which blocks users from the system rather than permit system self-interference to reach unacceptable levels. The method thus maintains the highest possible quality of service given the demand on the system.

FIG. 4 depicts a section of a cell map for a cellular telecommunication system. Each circle represents a cell which is assigned units of capacity which may be defined in terms of time separation (TDMA), frequency separation (FDMA), code separation (CDMA), or any combination of these methods. Since the method is not dependent on the specific way used to separate users, a "reuse unit" is defined as some unit of capacity which is to be assigned either to a cell or to an individual subscriber unit within the cell. It is these reuse units which are physically separated in order to avoid interference.

As shown in FIG. 4, the system requires more capacity in the shaded cell. Each of the cells surrounding the shaded cell is carrying traffic to some degree, and therefore have already been assigned a number of reuse units. The goal is to assign a reuse unit to the shaded cell to carry the traffic demand while minimizing the mutual self-interference incurred from the new assignment.

One of the methods for managing and reusing channels in accordance with a preferred embodiment of the present invention is shown in FIG. 5. Briefly, this method uses an iterative "maximum distance" search in which it initially attempts to assign a new user to a channel for which all currently active channels that potentially interfere are beyond the radio horizon of the cell in which the new user is located. If this fails, the allowable distance for an interfering channel is reduced and another attempt is made to find an available channel for the new user. This search is repeated for smaller allowed separation between the new channel and potential interfering channels until an available channel is located.

As shown in FIG. 5, method 100 begins in step 102 by receiving a reuse unit request from a subscriber unit. In step 104, method 100 sets reuse unit acceptance criterion for a most restrictive condition. This may involve, such as shown in FIG. 4, drawing a "large" radius circle centered from the center of the shaded cell. ("Large" is defined as a distance so big that identical reuse unit assignments physically separated by that distance will incur negligible mutual interference.) The region within the circle will be referred to as the "exclusion zone".

Method 100 then tests in step 106 all reuse units and determines in step 108 whether an acceptable reuse unit is available. For example, method 100 examines the entire list of reuse units available to the system as candidates for addition to the shaded cell. A candidate reuse unit may only be used in the shaded cell if no cell whose center lies within the exclusion zone is already using that reuse unit. If such a reuse unit can be found, method 100 will assign it to the shaded cell. If an acceptable reuse unit is found, the subscriber unit is assigned the reuse channel in step 110.

Otherwise, method 100 determines in step 112 whether the criterion is at the minimum distance or acceptance level. If no such cell can be found, method 100 reduces in step 114 the radius of the exclusion zone by some suitable factors and repeats steps 106, 108 and 112. For example, if such a reduction in the exclusion zone would put the radius below the minimum radius required to maintain system quality of service, then the shaded cell cannot be assigned the additional capacity and method 100 blocks users from entry into the system in step 116. Method 100 repeats steps 106, 108, 112 and 114 until an acceptable reuse channel is found, or until a channel is found not to be available and the subscriber is blocked from establishing telecommunication in step 116.

Note that method 100 maintains the largest possible physical separation between users having the same reuse unit, given the current system loading level. This permits very high quality of service in lightly loaded areas, with optimal system performance maintained right down to the minimum acceptable quality of service defined by the reuse distance floor as loading levels increase.

There are variants on the basic method shown in FIG. 3. It is possible that varying propagation delays and Doppler shifts between a user and multiple satellites will cause even different reuse units to interfere. (This is referred to as "loss of orthogonality" between reuse unit.) The basic algorithm is easily extended to take this loss of orthogonality into account. For example, if a reuse unit A may interference with reuse units B and C due to differential delay or Doppler, then one of the variation of method 100 is to modify step 106 to disallow the reuse units B and C within the exclusion zone in addition to reuse unit A.

Another variation is to modify the rules defining the exclusion zone from a simple circle with a given radius to cells which take into account the directional antenna isolation offered by the system antennas. The exclusion zone would then be defined as the region where all cells within the region provide a signal strength at the center of the shaded cell in excess of some threshold. The signal strength threshold would then be varied in the same way as the exclusion zone radius was varied in step 108 of method 100 shown in FIG. 5.

Another modification of method 100 is to add a minimum distance requirement when testing for acceptable reuse units in step 108 of method 100. If the search fails to find a suitable channel beyond the minimum distance, the user is denied access to the system. An additional modification of step 108 of method 100 is to allow less separation in areas where the antenna patterns provide more isolation between potentially interfering channels. Moreover, a different minimum may be used for on-going calls than for acquisition requests for new calls.

An alternative to the "maximum distance" iterative method is a minimum interference cost method 150 shown in FIG. 6. In this method 150, the channel space is searched

one time and an interference cost is derived for each unused channel. At the end of the search, the lowest cost channel is assigned to the new user. Method **150** has the advantage of only requiring one search through the available channel space for each channel assignment. Method **150** also has a speed advantage in areas of heavy channel demand, but is slower for less congested areas.

As shown in FIG. **6**, method **150** receives in step **152** a reuse unit request. Next, method **150** generates a signal-to-interference ratio (S/I) cost function for each reuse unit based on cell location and existing traffic. Method **150** may use an average signal-to-interference ratio (S/I) that would result if a particular channel were to be used in the new user's cell. This cost function could be computed a particular point such as the center of the cell. However, it is more effective to compute the average S/I for a number of points in the cell. Examples of points that could be used are a group of points evenly spaced around the cells perimeter or a grid of points that covers the overall area of the cell.

Alternative cost functions may be used for the interference cost method. For example, the components of the S/I calculation can be weighted so that particular interference sources (e.g., reuse channels, time slide, or frequency slide) are preferentially permitted or eliminated. Another function may use only the S/I due to the most powerful interference source as the cost. This increased the speed of the algorithm at the cost of some accuracy. Since the cost function is an average, it is possible (but not necessary) to condition the interference cost on the statistics of environmental factors such as differential fading.

As shown in FIG. **6**, after method **150** generates the cost function for each reuse unit in step **154**, method **150** determines in step **156** whether an acceptable reuse unit is available. If there is an acceptable reuse unit that is available, method **150** assigns in step **158** the reuse unit with lowest cost. Otherwise, method **150** determines that a channel is not available, so the subscriber unit is blocked in step **160**.

An important variation to method **150** is to require a minimum cost before a channel is assigned. Another variation is to permit a channel assignment as soon as a low enough cost channel is found. This increases the speed of method **150**.

An important point to consider in devising an adaptive reuse method based on an S/I cost function is that the interference paths may not be reciprocal. For example, in the situation in FIG. **2**, subscriber unit A could interfere with subscriber unit B's channel, while subscriber unit B would not interfere with subscriber unit A's channel. This is common in LEO-based systems because the differential Doppler and propagation delay is seldom symmetrical between two users and two satellites. This lack of reciprocity becomes more pronounced in practical systems where a large number of interferers may combine to exceed the interference threshold of any particular user.

The lack of reciprocal interference can be incorporated into an adaptive reuse method as follows. When a new reuse unit is tested for admissibility, both the potential interference it might see and the potential interference it could cause to previously assigned reuse units is tested. The specific test depends on the particular cost function algorithm.

The adaptive reuse methods can be executed in real-time using the actual instantaneous system demand. This may, however, be impractical in some cases such as small satellites where computational power could be excessive. In addition, to be effective in a satellite system, the methods must be aware of the channel assignments in all other satellites where interference could occur. One solution is to generate channel assignments for each satellite in a central system control facility using predicted demand based on traffic history.

When the adaptive reuse method is used in a non-real time manner, the process proceeds as described above. The predicted demand is used in the adaptive reuse algorithm and a list of available channels are compiled for each satellite for each time interval. When the adaptive method is used, however, a cost index is included in the table for each channel at each time. When a satellite actually assigns a traffic channel, it always uses the lowest cost channel that is available.

It will be appreciated by those skilled in the art that the present invention allows for efficient managing and reusing a channels. The present invention reuses frequency and time assignments in different areas of system coverage to achieve efficient use of the available frequency spectrum. The adaptive nature of the methods maintains high capacity at the minimum interference level that can be achieved at that capacity.

The method described herein assigns channels to maintain efficient spectrum use and minimize interference through other paths.

In fixed reuse patterns, interference is higher than necessary for the required capacity. These methods match the interference level to the demand. When the system is lightly loaded, the interference is quite low. As the demand increases, the reuse is increased to provide more capacity at the cost of increased reuse.

Another advantage is since every channel assignment is based on minimizing its interference to all other channels simultaneously in use, the reuse pattern is optimized for the current user distribution.

Accordingly, it is intended by the appended claims to cover all modifications of the invention which fall within the true spirit and scope of the invention.

What is claimed is:

1. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) restricting interference potential by controlling at least one of spacing between interfering channels, time slide, frequency slide and antenna pattern and by searching through all unused channels and checking the interference potential of each of the unused channels against all channels that are already assigned; and

(c) assigning one of the unused channels with the lowest interference potential to the user.

2. A method as recited in claim **1**, wherein step (b) comprises the step of terminating the search as soon as one of the unused channels which meets minimum interference criterion is found.

3. A method as recited in claim **1**, wherein step (b) comprises the step of predicting interference from a combination of the unused channels.

4. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) using at least one of spacing between interfering channels, time slide, frequency slide and antenna pattern to predict interference from a combination of the unused channels;

(c) searching through all unused channels and checking the interference potential of each of the unused channels against all channels that are already assigned; and

(d) assigning one of the unused channels with the lowest interference potential to the user.

5. A method as recited in claim **1**, wherein step (c) comprises the step of assigning one of the unused channels if it meets minimum interference criterion.

6. A method as recited in claim 1. further comprising the step of denying access to the telecommunication system if none of the unused channels meet minimum interference criterion.

7. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) determining whether a channel for which all currently active channels that potentially interfere are beyond a distance from where the user is located;

(c) assigning the channel to the user if step (b) finds a channel that does not interfere with any of the currently active channels;

(d) reducing the distance by a predetermined amount;

(e) determining whether a channel for which all of the currently active channels that potentially interfere are beyond the reduced distance; and

(f) assigning the channel to the user if step (e) finds a channel that does not interfere with any of the currently active channels.

8. A method as recited in claim 7, further comprising the steps of:

(g) repeating steps (d)–(f) until a channel is found that does not interfere with any of the currently active channels; and

(h) blocking the user's access to the telecommunication system if a channel is not found that does not interfere with any of the currently active channels.

9. A method as recited in claim 7, further comprising the steps of:

(g) repeating steps (d)–(f) until a channel is found that does not interfere with any of the currently active channels or the reduced distance is at a minimum distance; and

(h) blocking access of the user to the telecommunication system if a channel is not found that does not interfere with any of the currently active channels or the reduced distance is a minimum distance.

10. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) determining whether a non-interfering channel exists based on at least one of propagation delays and Doppler shifts of a plurality of currently active channels and physical distance of the currently active channels from where the user is located; and

(c) assigning the channel to the user if step (b) finds a channel that does not interfere with any of the currently active channels.

11. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) determining whether a non-interfering channel exists based on at least one of propagation delays and Doppler shifts of currently active channels and a region of an exclusion zone; and

(c) assigning the channel to the user if step (b) finds a channel that does not interfere with any of the currently active channels.

12. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) determining whether a non-interfering channel exists based on at least one of propagation delays and Doppler shifts of a plurality of currently active channels and a region of an exclusion zone; and

(c) assigning the channel to the user if step (b) finds a channel that does not interfere with any of the currently active channels.

13. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user for a channel;

(b) determining whether a non-interfering channel exists based on at least one of propagation delays and Doppler shifts of a plurality of currently active channels and a physical distance of the currently active channels from where the user is located;

(c) repeating step (b) until a channel is found that does not interfere with any of the currently active channels or the physical distance is reduced to a minimum distance;

(d) assigning the channel to the user if a channel that does not interfere with any of the currently active channels is found; and

(e) blocking the user's access to the telecommunication system if a channel is not found that does not interfere with any of the currently active channels or the distance is reduced to a minimum distance.

14. A method for managing and reusing channels in a telecommunication system, the method comprising the steps of:

(a) receiving a request from a user located in a cell for a channel, wherein the request includes the cell's location;

(b) generating for each of a plurality of unused channels a cost of interference based on the cell's location and an average signal-to-interference ratio of a corresponding one of the unused channels used at various points in the cell; and

(c) assigning one of the unused channels having the lowest cost of interference to the user.

15. A method as retired in claim 14, wherein step (c) comprises the step of assigning the one of the unused channels having an interference cost being equal to or greater than a minimum interference cost of interference.

16. A method for managing and reusing channels in a telecommunication system, the telecommunication system comprising a plurality of satellites and subscriber units, the method comprising the steps of:

(a) determining an anticipated demand for a duration of a planning interval;

(b) restricting interference potential by controlling at least one of spacing between interfering channels, time slide, frequency slide and antenna pattern and by searching through all unused channels and checking the interference potential of each of the unused channels against all channels that are already assigned;

(c) allocating one of the unused channels with the lowest interference potential to a cell within which demand is expected; and

(d) propagating movement of the satellites, location of the subscriber units, and interference sources forward in time to create a preplanned allocation of channels with minimum interference potential.

* * * * *

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United States Patent [19]

Rudrapatna et al.

[11] Patent Number: 5,592,470

[45] Date of Patent: Jan. 7, 1997

[54] **BROADBAND WIRELESS SYSTEM AND NETWORK ARCHITECTURE PROVIDING BROADBAND/NARROWBAND SERVICE WITH OPTIMAL STATIC AND DYNAMIC BANDWIDTH/CHANNEL ALLOCATION**

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[73] Assignee: **AT&T**, Holmdel, N.J.

[21] Appl. No.: **361,355**

[22] Filed: **Dec. 21, 1994**

[51] **Int. Cl.**[6] **H04J 3/26**; H04L 5/22

[52] **U.S. Cl.** **370/320**; 348/7; 348/12; 348/13; 375/200; 370/468; 370/477; 370/907

[58] **Field of Search** 370/18, 26, 32, 370/35, 38, 45, 50, 91, 85.13, 85.14, 95.1, 95.3, 118, 60, 60.1, 94.1, 94.2; 375/200, 201, 202, 205, 211, 212; 348/6, 7, 12, 13, 5.5

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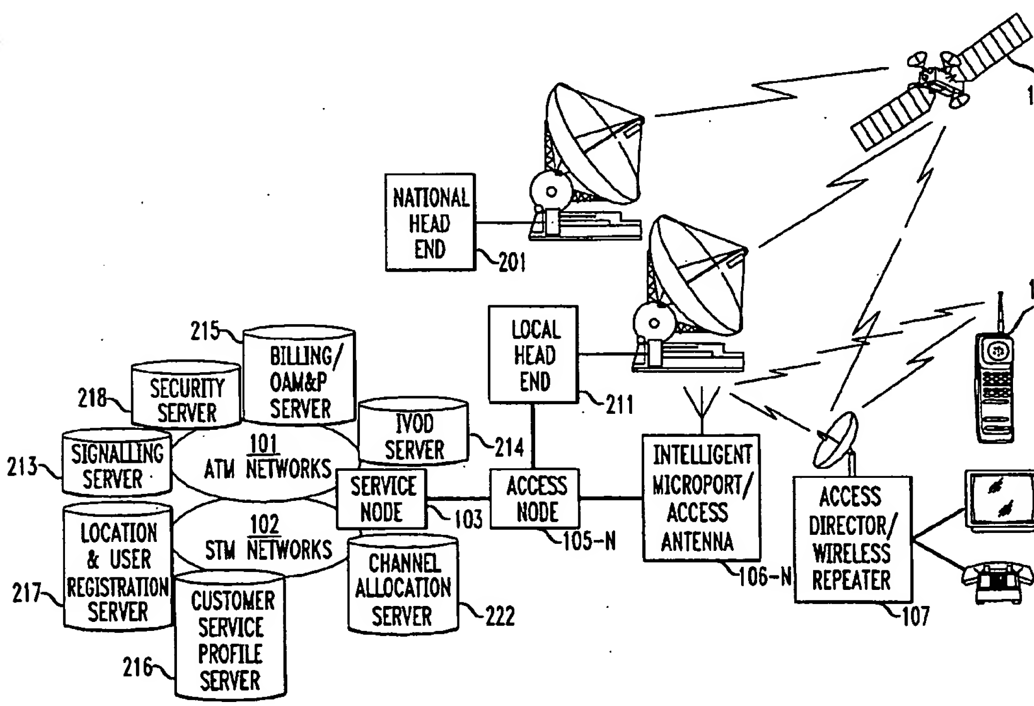
Primary Examiner—Alpus H. Hsu
Assistant Examiner—Ricky Q. Ngo
Attorney, Agent, or Firm—A. G. Steinmetz

[57] **ABSTRACT**

A wireless broadband communication system architecture is structured to provide an array of narrowband and broadband services to an end user on demand. The bandwidth of delivery is dynamically adjusted to deliver and satisfy service requirements by utilizing the appropriate bandwidth on demand. Bandwidth-on-demand is provided in accord with the invention by rearranging spectrum allocations so that a particular band spectrum is convertibly used to accomplish different purposes depending on present allocations and active applications of the system. The communications system is designed to utilize wireless communication for end point delivery to both fixed and potable terminals. The system supplies basic telephone service, wireless ISDN service, wireless data service, wireless multimedia service and various other wireless broadband service including types of interactive and broadcast video.

28 Claims, 8 Drawing Sheets



03/09/2004, EAST Version: 1.4.1

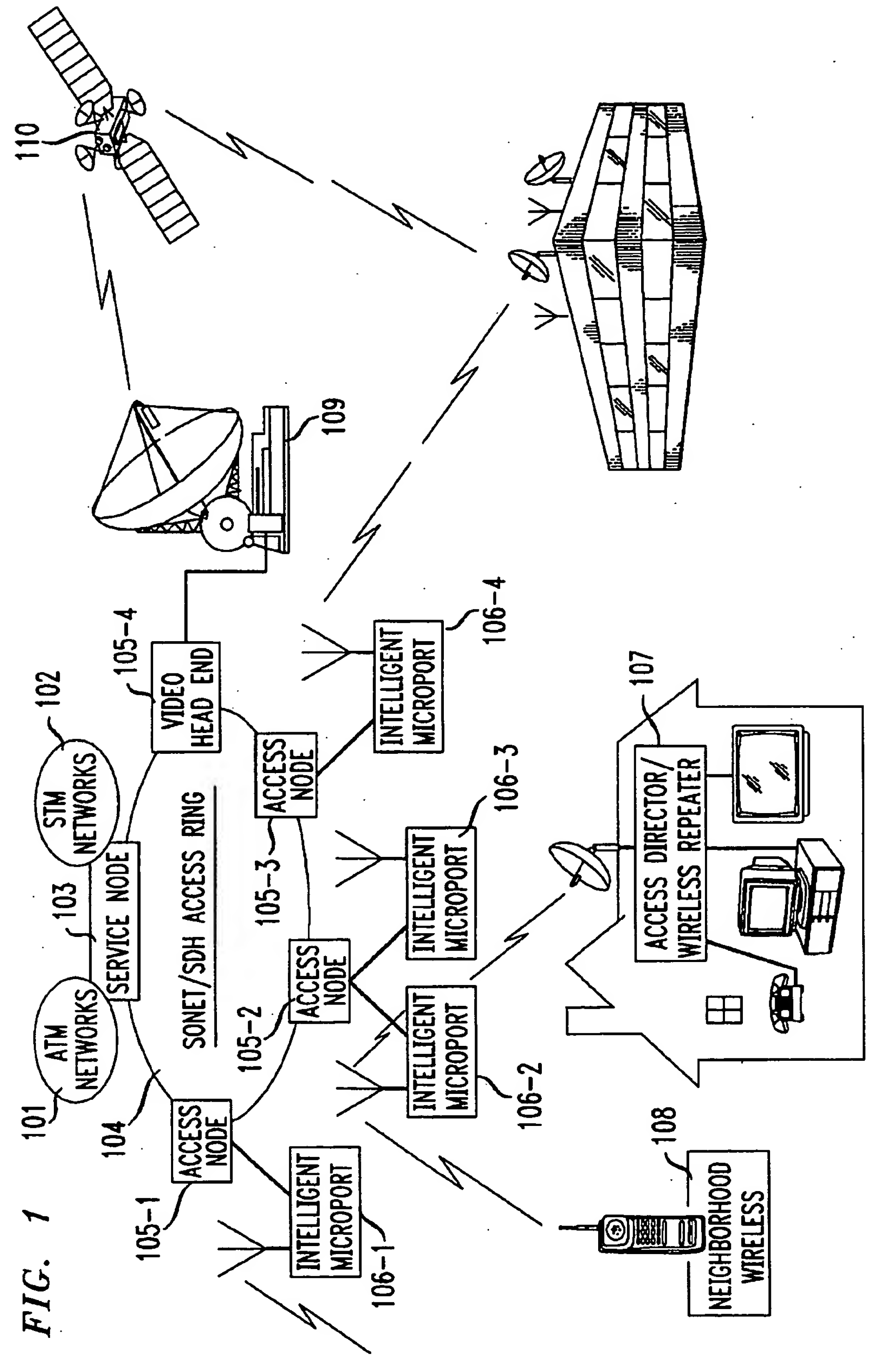

110
109
ATM NETWORKS
101
STM NETWORKS
102
SERVICE NODE
103
VIDEO HEAD END
105-4
SONET/SDH ACCESS RING
104
ACCESS NODE
105-1
ACCESS NODE
105-2
ACCESS NODE
105-3
INTELLIGENT MICROPORT
106-1
INTELLIGENT MICROPORT
106-2
INTELLIGENT MICROPORT
106-3
INTELLIGENT MICROPORT
106-4
ACCESS DIRECTOR/ WIRELESS REPEATER
107
NEIGHBORHOOD WIRELESS
108

FIG. 1

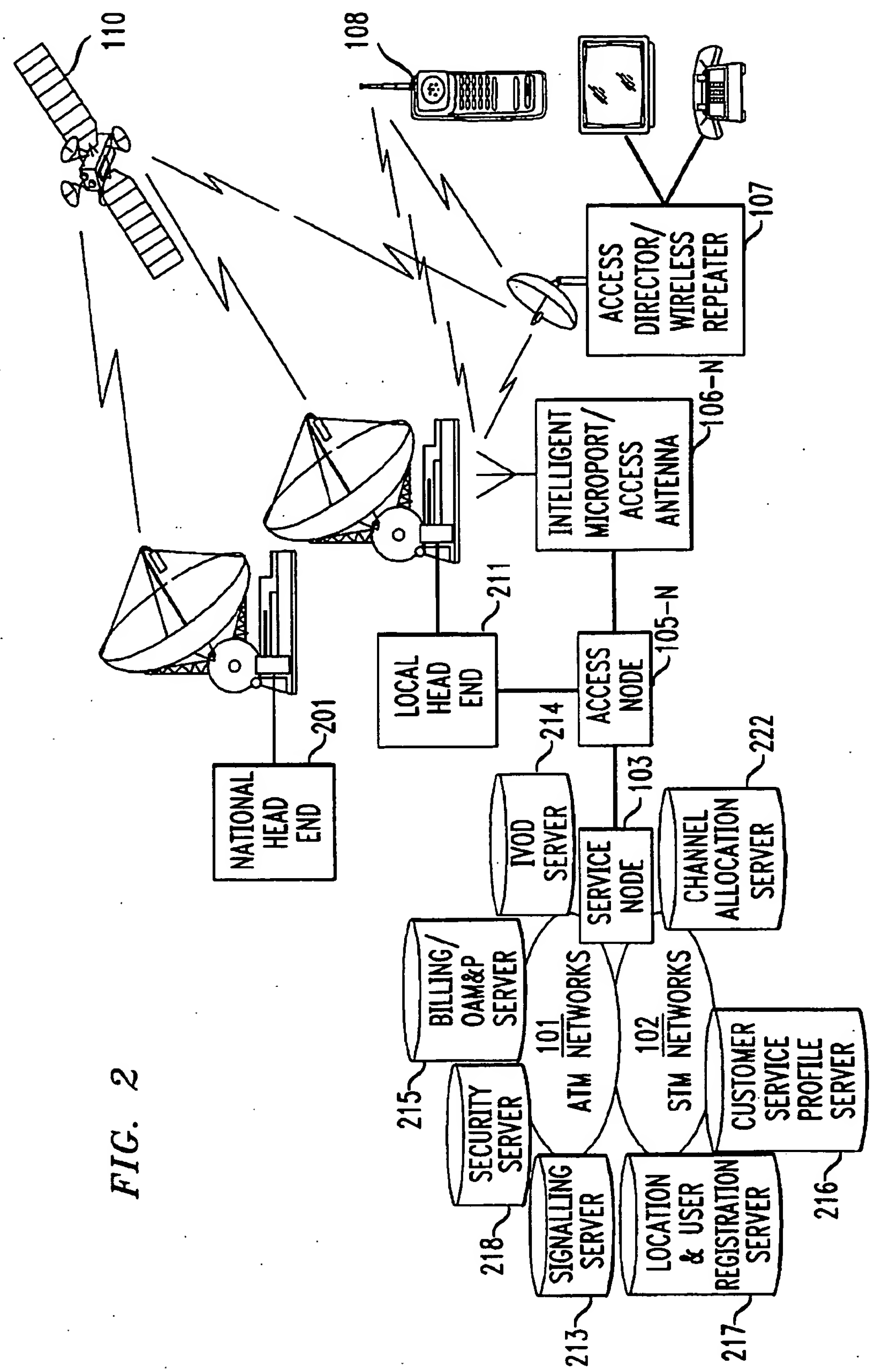

110
108
107
ACCESS DIRECTOR/ WIRELESS REPEATER
106-N
INTELLIGENT MICROPORT/ ACCESS ANTENNA
211
LOCAL HEAD END
105-N
ACCESS NODE
214
201
NATIONAL HEAD END
IVOD SERVER
103
SERVICE NODE
222
CHANNEL ALLOCATION SERVER
BILLING/ OAM&P SERVER
215
101 ATM NETWORKS
102 STM NETWORKS
SECURITY SERVER
CUSTOMER SERVICE PROFILE SERVER
218
SIGNALLING SERVER
LOCATION & USER REGISTRATION SERVER
216
213
217

FIG. 2

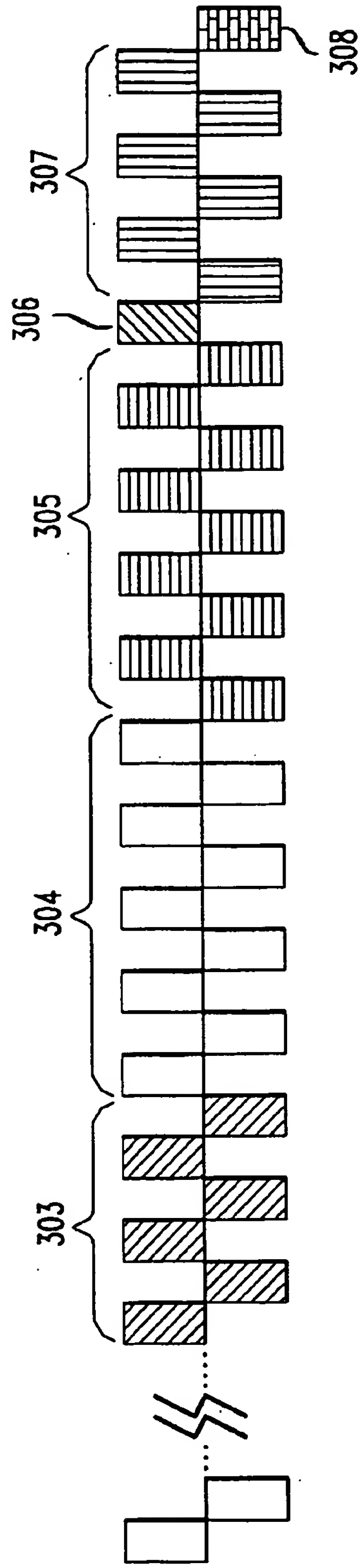


FIG. 3

FIG. 4

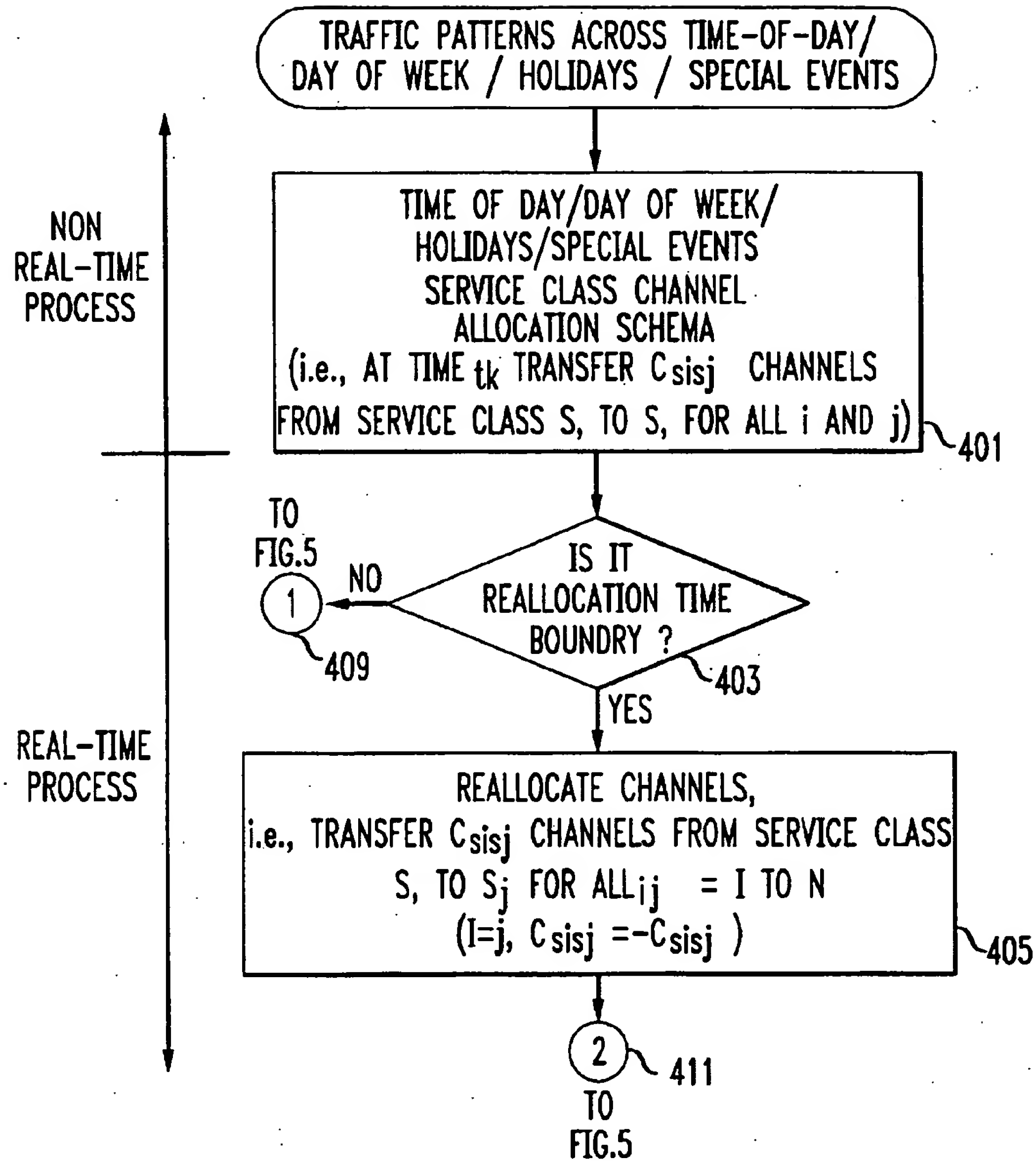
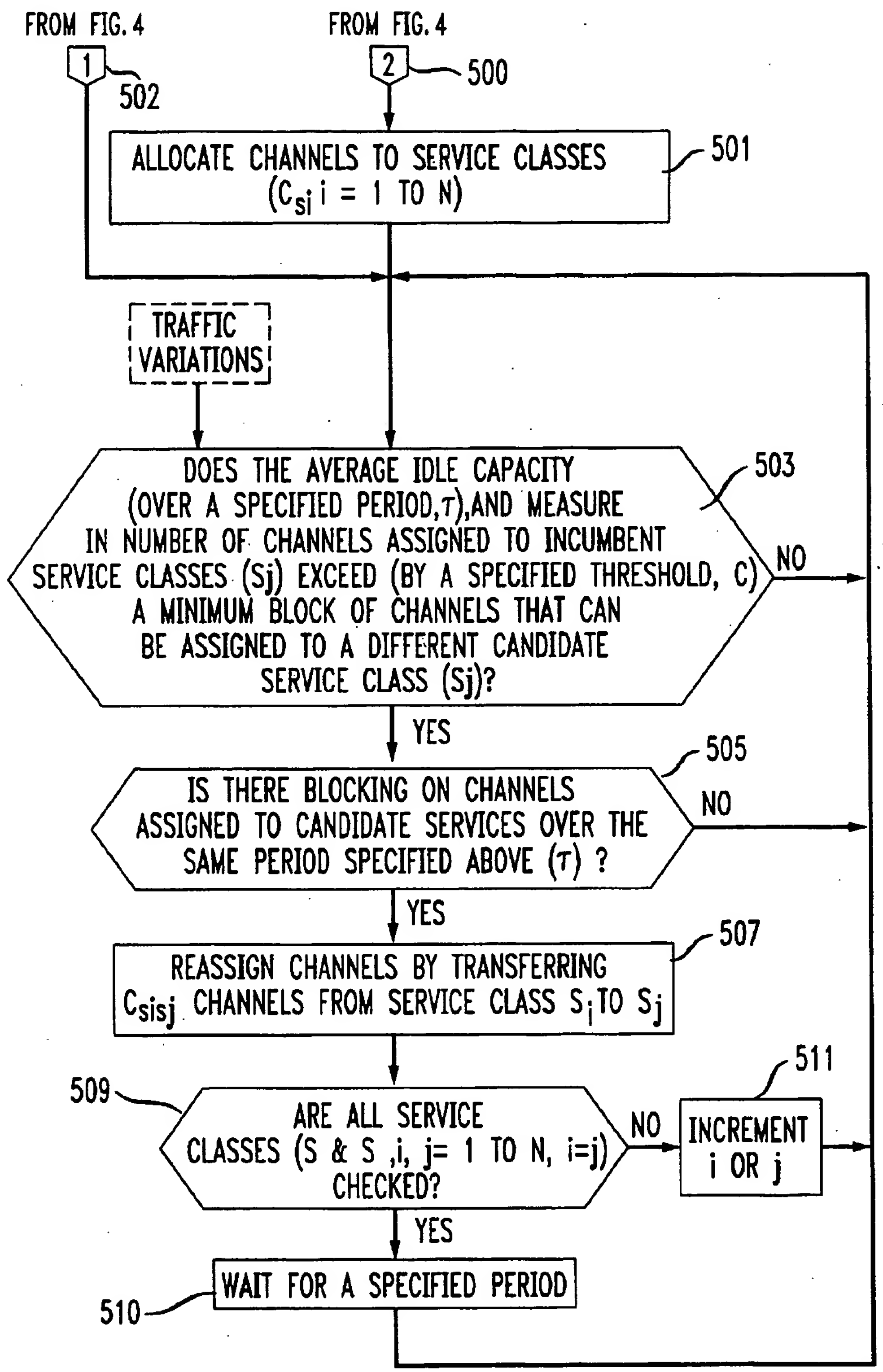

TRAFFIC PATTERNS ACROSS TIME-OF-DAY/ DAY OF WEEK / HOLIDAYS / SPECIAL EVENTS
NON REAL-TIME PROCESS
TIME OF DAY/DAY OF WEEK/ HOLIDAYS/SPECIAL EVENTS SERVICE CLASS CHANNEL ALLOCATION SCHEMA (i.e., AT TIME tk TRANSFER Csisj CHANNELS FROM SERVICE CLASS S, TO S, FOR ALL i AND j)
401
TO FIG.5
NO
1
409
IS IT REALLOCATION TIME BOUNDRY ?
403
YES
REAL-TIME PROCESS
REALLOCATE CHANNELS, i.e., TRANSFER Csisj CHANNELS FROM SERVICE CLASS S, TO Sj FOR ALLij = I TO N (I=j, Csisj =-Csisj)
405
2
411
TO FIG.5

FIG. 5



FROM FIG. 4
1
502
FROM FIG. 4
2
500
ALLOCATE CHANNELS TO SERVICE CLASSES (Csi i = 1 TO N)
501
TRAFFIC VARIATIONS
DOES THE AVERAGE IDLE CAPACITY (OVER A SPECIFIED PERIOD, τ), AND MEASURE IN NUMBER OF CHANNELS ASSIGNED TO INCUMBENT SERVICE CLASSES (Sj) EXCEED (BY A SPECIFIED THRESHOLD, C) A MINIMUM BLOCK OF CHANNELS THAT CAN BE ASSIGNED TO A DIFFERENT CANDIDATE SERVICE CLASS (Sj)?
503
NO
YES
IS THERE BLOCKING ON CHANNELS ASSIGNED TO CANDIDATE SERVICES OVER THE SAME PERIOD SPECIFIED ABOVE (τ) ?
505
NO
YES
REASSIGN CHANNELS BY TRANSFERRING Csisj CHANNELS FROM SERVICE CLASS Si TO Sj
507
509
ARE ALL SERVICE CLASSES (S & S ,i, j= 1 TO N, i=j) CHECKED?
NO
INCREMENT i OR j
511
YES
WAIT FOR A SPECIFIED PERIOD
510

FIG. 6

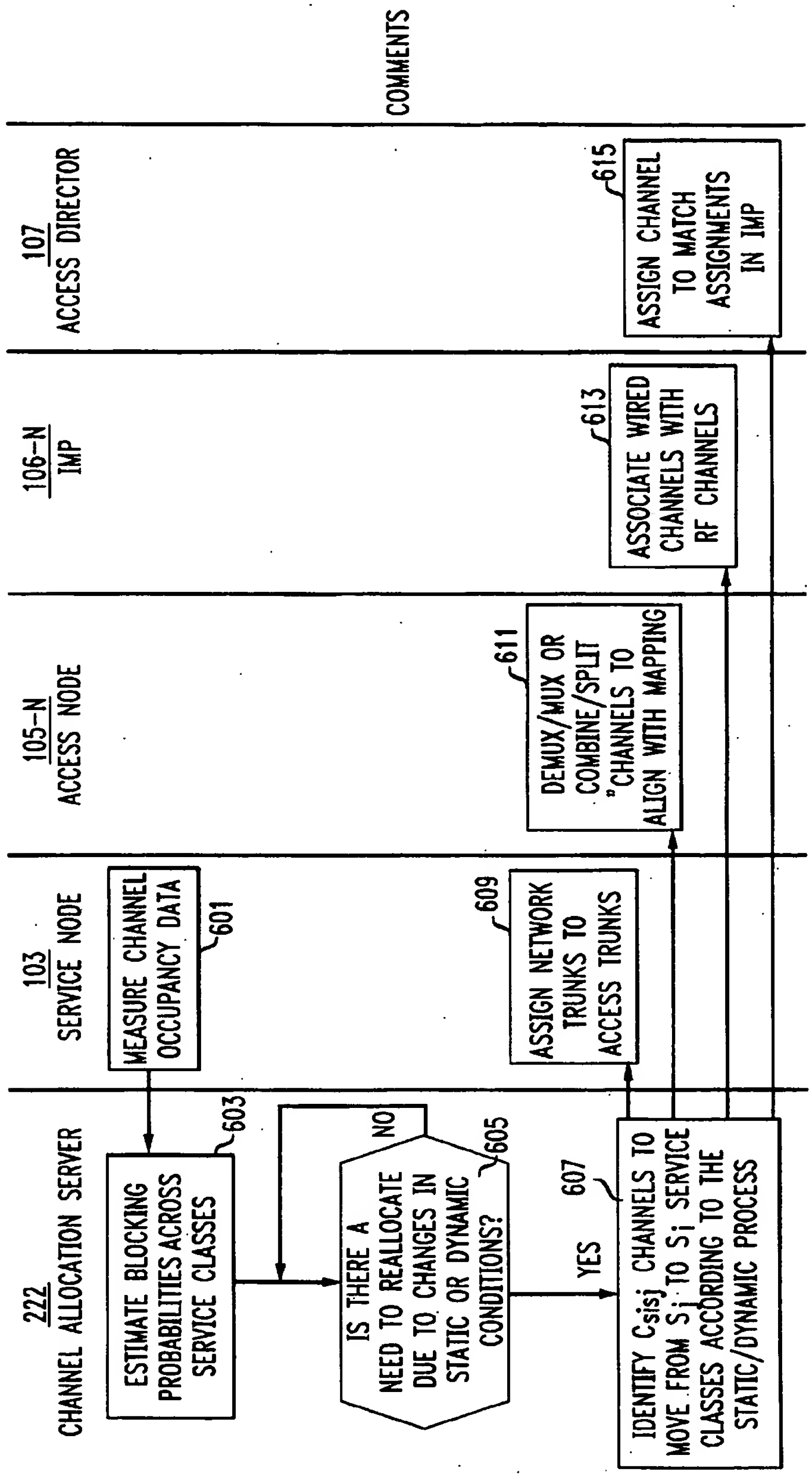

222
CHANNEL ALLOCATION SERVER
103
SERVICE NODE
105-N
ACCESS NODE
106-N
IMP
107
ACCESS DIRECTOR
COMMENTS
MEASURE CHANNEL OCCUPANCY DATA
601
ESTIMATE BLOCKING PROBABILITIES ACROSS SERVICE CLASSES
603
IS THERE A NEED TO REALLOCATE DUE TO CHANGES IN STATIC OR DYNAMIC CONDITIONS?
605
NO
YES
IDENTIFY Csisj CHANNELS TO MOVE FROM Si TO Sj SERVICE CLASSES ACCORDING TO THE STATIC/DYNAMIC PROCESS
607
ASSIGN NETWORK TRUNKS TO ACCESS TRUNKS
609
DEMUX/MUX OR COMBINE/SPLIT CHANNELS TO ALIGN WITH MAPPING
611
ASSOCIATE WIRED CHANNELS WITH RF CHANNELS
613
ASSIGN CHANNEL TO MATCH ASSIGNMENTS IN IMP
615

FIG. 7

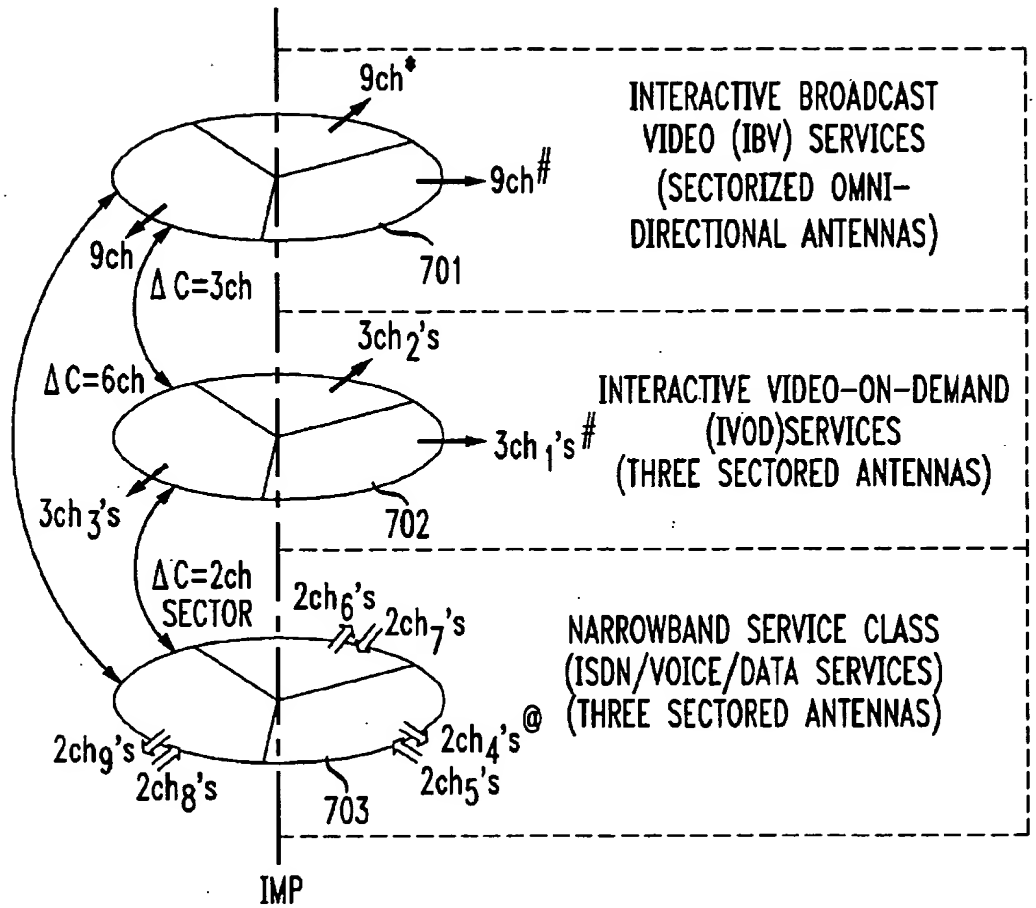

9ch*
9ch#
9ch
ΔC=3ch
701
INTERACTIVE BROADCAST VIDEO (IBV) SERVICES (SECTORIZED OMNI-DIRECTIONAL ANTENNAS)
3ch2's
ΔC=6ch
3ch1's#
3ch3's
702
INTERACTIVE VIDEO-ON-DEMAND (IVOD)SERVICES (THREE SECTORED ANTENNAS)
ΔC=2ch SECTOR
2ch6's
2ch7's
2ch9's
2ch8's
2ch4's@
2ch5's
703
NARROWBAND SERVICE CLASS (ISDN/VOICE/DATA SERVICES) (THREE SECTORED ANTENNAS)
IMP

FIG. 8

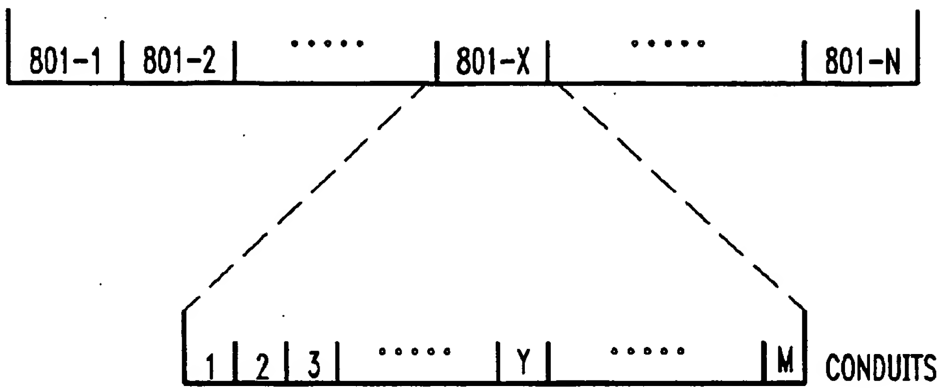
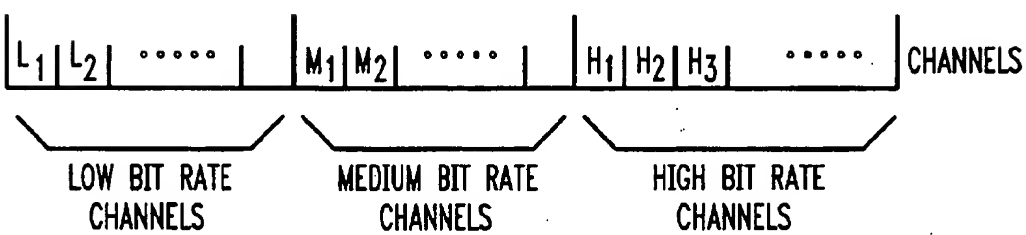

801-1
801-2
801-X
801-N
1
2
3
Y
M
CONDUITS

FIG. 9


L1
L2
M1
M2
H1
H2
H3
CHANNELS
LOW BIT RATE CHANNELS
MEDIUM BIT RATE CHANNELS
HIGH BIT RATE CHANNELS

BROADBAND WIRELESS SYSTEM AND NETWORK ARCHITECTURE PROVIDING BROADBAND/NARROWBAND SERVICE WITH OPTIMAL STATIC AND DYNAMIC BANDWIDTH/CHANNEL ALLOCATION

FIELD OF THE INVENTION

This invention relates to communication system architectures and to a particular network architecture for providing narrowband/broadband two-way point-to-multipoint services to fixed and portable terminals in high teledensity areas. It is specifically concerned with a communication system that utilizes wireless transmission and dynamically allocates channels/bandwidth for specific present applications.

BACKGROUND OF THE INVENTION

Telecommunication systems provide numerous services requiting both broadband and narrowband capabilities to the corporate and individual subscriber. These services normally require that each customer be provided with wide bandwidth communications transmission media (e.g., cable or fiber) for broadband services and with narrowband transmission media (e.g., twisted pair) for narrowband services if all needed services are to be accommodated. This hard-wired physical media-based capability is expensive to install and maintain and the associated capital may be unrecoverable if the end user decides to change the service provider after installation. These same costs may also limit system deployment if these costs become prohibitive and fail to yield profitable life cycle economics.

However, wireless systems have inherent flexibility because of their untethered nature. If the end user changes carriers, no capital is stranded, since the wireless termination device can be recovered and redeployed.

SUMMARY OF THE INVENTION

A wireless broadband communication system architecture is structured to provide an array of narrowband and broadband services on demand to an end user. The system embodied by this invention maximizes frequency reuse by a judicious combination of spread spectrum techniques and time division multiplexing, and matching service requirements with appropriate sectoring of radiant signaling energy. The bandwidth of delivery is dynamically adjusted to satisfy service requirements by providing the appropriate bandwidth needed. Bandwidth-on-demand is provided in accord with the invention by rearranging (i.e. remapping) spectrum allocation to simultaneously achieve two objectives: (1) assign users channels matched to their requirements, and (2) rearrange channel assignments to maximize spectrum utilization. The communications system is designed to utilize wireless communication for end point delivery to fixed site customer areas and portable customer terminals. The system supplies basic telephone service, wireless ISDN service, wireless data service, wireless multimedia service, and various other wireless broadband services including interactive video and broadcast video. Furthermore, the system provides signaling capability in support of all the services.

Efficient use of spectrum is achieved at various levels of the system. At one level, channel assignment is performed in response to varying demand for different classes of service. In another aspect, conduits (which are subdivisions of channels) are varied in bit rate to accommodate service bandwidth requirements as long as the channels' conduits conform to an average throughput. In yet another aspect, service bandwidth requirements are matched to channels that are divided into high, medium and low bandwidth in order to achieve spectral efficiency.

In a particular scenario making use of the invention, the communication system provides bandwidth on demand by utilizing a combination of spread spectrum technique (CDMA) and time division multiplexing (TDM) operating over a broadband spectrum that is allocated to specific channels on demand. The CDMA/TDM signal is transmitted between the system network and to a customer premise dynamic access director station. The use of CDMA/TDM along with signal compression techniques allows the use of spectrum that up until now has only supplied a few channels for a small subset of services.

Spectral efficiency is enhanced by allocating/sharing the same bandwidth/channels to differing services based on a demand schedule matched to demand patterns. In another scenario using the interface, channels are allocated to services on a demand-driven basis.

In addition the network architecture provides for a set of network servers, and signaling/control means between the servers and end user devices for providing integrated services on an end-to-end network basis.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a pictorial schematic of a broadband wireless network topology embodying the principles of the invention;

FIG. 2 is a functional schematic of a broadband wireless network architecture embodying the principles of the invention;

FIG. 3 is a graph of illustrative spectrum allocation in accord with the invention;

FIG. 4 is a flowchart illustrating a method of static channel assignment to meet predictable service demand variations;

FIG. 5 is a flowchart illustrating a method of dynamic channel assignment to meet service demands;

FIG. 6 is a graphical depiction of the distribution of procedures to implement static and dynamic channel assignments;

FIG. 7 is a graph of an incremental channel reassignment process across service classes;

FIG. 8 shows how the spectrum is partitioned into channels and conduits; and

FIG. 9 illustrates a subchannel assignment scheme for servicing broadband (i.e., video) services.

DETAILED DESCRIPTION

System Network Topology For Wireless Network With Spectrum Allocation

FIG. 1 illustrates one version of a network topology of a broadband wireless network embodying the principles of the invention. An ATM (asynchronous transfer mode) network **101** and a STM (synchronous transfer mode) network **102** are shown connected to a service node **103** coupled in turn to a fiber based SONET/SDH access ring **104**. The use of a fiber based SONET/SDH ring for access and link purposes is for illustrative purposes and is not essential for the disclosed Illustrative network. A star network using non-fiber transmission, including point-to-point microwave and/

or infrared communication could just as easily be used. Access nodes 105-1 to 105-4 couple the SONET/SDH access ring 104 to a plurality of access antennas or intelligent microports (IMP) 106-1 to 106-4. The intelligent microport 106-2 is shown connected by wireless to an access director or wireless repeater 107 at a residential customer premise. This access director/wireless repeater contains a plurality of equipment functionality [including a telephone, ISDN terminals data communication devices (e.g., PC), signaling devices/adjuncts, television/set-top boxes, multimedia worksataions, etc] supplying a broad array of narrowband/broadband services, each of which requires differing bandwidth capability. The microport 106-2 is also shown as directly serving a wireless handset 108 external to the customer premise. A microport 106-4 is shown coupling service to an industrial/office site in a manner similar to that of the residence premises. A satellite ground station 109 is shown connecting the SONET/SDH access ring 104 to a satellite 110 via access node 105-4. Communication between the SONET/SDH access ring 104 and the end user recipients is by wireless, permitting the spectrum to be partitioned into multiple channels of sufficient bandwidth as required by a particular service or application.

Functional Partitioning of the Network to Achieve Optimal Spectral Implementation

An architecture suitable for the broadband wireless network is shown in the FIG. 2 in terms of the communication of the network to a particular end user. A channel allocation server 222 is provided to identify and store information regarding uses of different services over time to control static and dynamic reallocations of spectrum to individual services.

A signaling server 213 provides signaling services to end user devices: Acting as a gateway between end user devices and the network's internal signaling system; distributing control data to other servers, such as billing/OAM&P (operations, administration, maintenance, and provisioning) data to billing/OAM&P server; etc. IVOD server 214 supports IVOD services, enhancements to normal video; (e.g., pause, rewind etc. interactivity), menu driven user interface, etc. Billing/OAM&P server 215 provides for integrated billing/OAM&P to end users across all services taking into account any special service options and plans (e.g., 60 minutes of any program per month for a fixed fee). Security server 218 provides for security authentication and fraud prevention services to service providers and to end users. Customer service profile server 216 stores end user data including subscriber server preferences, etc. Location and user registration server 217, contains real time data on a user's current location and service area related data.

Signaling server 213, IVOD server 214, security server 218, billing/OAM&P server 215, customer service profile server 216, location and user registration server 217 and the channel allocation server 222 are coupled to the ATM network 101, STM network 102, and/or the service node 103. The ATM network 101 and STM network 102 are connected to a service node 103 which is in turn connected to an access node 105-N. A national headend 201 is connected to the local headend 211 via a satellite 110 and satellite ground station 109. The local headend 211 is also connected to an access node 105-N. An intelligent microport (access antenna) 106-N provides the air interface to the access director 107, which is in turn connected to the premise equipment or neighborhood wireless terminal 108 by either internal wiring or by a short air interface.

The service node 103 performs traffic grooming (e.g. aligning radio frequency/access lines to land line trunks and to channels in low, medium and high arrays to sub-channels with low, medium and high bit rate services) and further performs circuit/synchronous transfer mode (STM) and cell/asynchronous transfer mode (ATM) switching. It is also a control for feature invocation and execution. The national headend 201 originates video/multimedia broadcast information for national distribution. A local headend 211 or the access director 107 receives the video/multimedia information for local distribution. The access node 105-N adds and drops trunks to the ring/access links and provides multiplexing and demultiplexing capability. The intelligent microport 106-N implements both narrowband and broadband services by supporting a variety of multiple air interfaces. It provides both static and dynamic channel allocation to meet changing service demands by providing bandwidth on demand. The access director 107 is a gateway/repeater providing a link between the microport and customer premises equipment (both wireless 108 and wired). The neighborhood wireless terminal 108, supports a broad array of services including wireless multimedia services.

Spectrum Allocation and Partitioning

Allocation or partitioning of available spectrum in accord with the principles of the invention is shown in the FIG. 3. A service channel map shows how various channels may be apportioned to various illustrative service classes. Blocks of channels each enabling a 6 or 10 MHz bandwidth are shown arranged linearly. Two channels 301 are shown distinct and isolated from the main array. These channels are dedicated to signaling for set up of connections and control of interactive commands. They also convey data useful in provisioning, billing/OAM&P, and maintaining services to end users on an end-to-end basis across all services in an integrated manner. This data communicated between the end user terminals and the network servers (213 through 222 in FIG. 2) include user identity, destination address, authentication service request codes, billing options, OAM&P messages, security/encryption code, service priority, location, grades of service requested, etc. This data is used by the network servers to provide services to end users in accordance with service requests. Channels 301 are wireless packet signaling channels in this embodiment and are comprised of two 6 MHz channels. In addition to utilizing channel 301, channel 308 (auxiliary packet response channel) could be used for this signaling and control messages, based on the amount that such messages need to be supported. Finally in addition to the dedicated channels (301, 308) these messages could also be exchanged via the same channels (303–307) use for the bearer services.

The total array of bearer channels covers a span of 198 MHz in this illustrative array. Channels 303 are narrowband service class access downlink channels. Channels 304 are downlink broadcast video service channels. Channels 305 are downlink interactive video on demand channels. The channels designated 306 provide guard spectrum for duplex filters/attenuation rolloff used in the network. Channels 307 are uplink narrowband service class access channels. Channel 308 is an auxiliary packet response channel. In the illustrative embodiment, channels designated 301 are bounded between 2150 MHz and 2162 MHz, and channels designated 303 through 308 are bounded between 2500 MHz and 2690 MHz. In this embodiment, both the frequencies and the bandwidth of the channels can be adapted to meet different requirements.

Static Channel Assignment Process

FIG. 4 flowcharts a process of static channel assignment. This process is repeated periodically to conform to the channel reassignments to known customer demands at specified intervals. The process assigns channels and bandwidth on the basis of established traffic patterns on specific days and at specific times of day. The instructions of the first process block **401** monitor the time of day and the day of the week and identify the occurrences of special days that are relevant to traffic demands. The traffic demands are categorized as to specific services and are evaluated with an allocation algorithm to specify channel transfers at time T_k according to: C_{sisj} from service class si to service class sj. A subsequent decision block **403** evaluates the data of block **401** to determine if static channel allocation is necessary. If it is not the flow proceeds, via terminal **409**, to a dynamic allocation flow process shown in the FIG. **5**. If a static allocation is needed the flow proceeds to instruction block **405** which specifies the reallocation of channels to meet the expected traffic demands. In the process the channel C_{sisj} is transferred from service class si to service class sj for all i and j where j=1 to N and i does not equal j and $C_{sisj}=-C_{sjsi}$. The flow then proceeds to the process of FIG. **5**, via terminal **411**.

Dynamic Channel Allocation Process

The process of dynamic assignments is described in the flowchart shown in FIG. **5**. It begins in terminal **500** which proceeds from the process shown in FIG. **4**. The initial instruction block **501** defines an existing allocation of channels and bandwidth to services. The flow process begins in response to a handoff from the static process of FIG. **4**, via terminal **502**, at the entry to decision block **503**. The instruction for block **503** determines idle channel capacity and compares the number of idle channels assigned to an incumbent service class (i.e. existing service assignments) over a specified time interval with a threshold of a minimum number of channel blocks Δ C that may within the the system be assigned to a different candidate service S_j. This minimum number corresponds to the transfer increment Δ C discussed herein below with reference to FIG. **7**. If the available idle capacity does not exceed this threshold, the process recycles to reevaluate the number of idle channels available for such purposes.

If it is determined that a sufficient number of channels exist to satisfy the threshold requirement, the subsequent decision block **505** determines if there is blocking on channels assigned to the candidate services over the same period investigated in the evaluation of the block **503**. If no such blocking exists the flow returns to the input in block **503**.

If such blocking is found to exist the process flow proceeds to instruction block **507** which controls the assignment of channels to transfer channels from service class si to service class sj. At the time of transfer it is determined if all service classes si to sj have been checked and evaluated. If it has the flow proceeds to instruction block **509** which halts the flow for a specified time interval. Instruction block **509** then returns the process to the input of block **503** where the dynamic assignment process resumes.

If all such service classes have not been evaluated, the flow proceeds to instruction block **511** which increments i or j and the flow returns to the input of block **503** where the dynamic assignment process resumes.

Network Distribution of Spectrum Allocation Functions

The procedures of channel assignment are distributed within the network system, as shown in FIG. **6**, with instruction block **601** being performed in the service node to measure channel occupancy data. The flow proceeds to decision block **605** in the channel allocation server which in process block **603** estimates the blocking probabilities in each service classes. The flow proceeds within the channel allocation server to decision block **605**, which determines if it is necessary to reallocate channel assignments due to changes in static or dynamic conditions. The process continuously recycles in this block if there is no need to reallocate spectrum. If there is a need to reallocate spectrum, the flow proceeds to instruction block **607** which identifies the channels C_{sisj} that are to be moved from si to sj service classes according to the defined static and dynamic assignment processes as described in the flow charts of FIGS. **4** and **5**.

The flow proceeds to instruction blocks **609**, **611**, **613** and **615** located in the service node, the access node, the intelligent microport and the access director, respectively. Instructions of block **609** assign network trunks to the access trunks. The instructions of block **611** demultiplex/multiples channels or combine/split channels to align mapping of blocks of channels. Instructions of block **613** associate wired channels with RF channels and instructions of block **615** assign channels to conform with assignments in the intelligent microport.

Spectrum Transfer Increments Illustrated

A graphical depiction of incremental channel reassignment in the system across service classes is illustrated in the FIG. **7** in which three circular charts **701**, **702** and **703** each define a different category of service classes. Each channel in the illustrative embodiment has a plurality of conduits of different bandwidth, with the conduits in each channel totaling 6 or 10 MHz. These conduits may be joined or separated and varied in bandwidth to form channels for specific service requirements. Each conduit or group of conduits is associated with supporting a specific service. These conduits are time slots in some applications (TDM) and are part of the shared spectrum band in other applications (CDMA).

The initial disk representation of disk **701**, in the illustrative embodiment, represents nine channels normally assigned to interactive broadcast video services. Disk **701** is sectorized into three 120 degree sectors each of which uses the same nine channels (i.e., a sectorized omni approach). A sectorized approach is used in place of omni radio signal radiation in order to use a single antenna for all services, to minimize power requirements, and minimize heat loads on the intelligent microport. Channels that are so sectorized are in effect omnidirectional, so that channel sectorization is designed to improve signal reception quality and limit geographical area covered to the requesting subscriber. The chosen sectorization scheme represents a single sectorized antenna that will support all the service classes depicted by the three representational graphical discs **701**, **702** and **703**.

The channels depicted on disk **702** are normally dedicated to interactive video services and include three sectors each of which includes three channels. It is apparent that the minimum increment of channels that can be transferred between the interactive broadcast video disc **701** and the interactive video-on-demand disc **702** is three channels total.

The first and second discs 701 and 702 are one way broadcast only signals from the intelligent micro port to the access antenna of the end user.

The third disk 703 depicts the collection of ISDN, voice and data services with four channels, paired to support duplex operations (e.g. two pairs related to each of the three sectors). The transfer increment between disk 702 and 703 is two channels per sector. All the channels on the discs 702 and 703 in the original set up are different in frequency from one another. The transfer increment between the first disk 701 and the third disc 703 is six channels total.

Intelligence for executing this transfer of channels preferably (though not necessarily) appears at the intelligent microport at the network access point. For example, a change of application of channels from disk 701 to disk 703 would require a minimum of six channels total to be transferred from disk 701 to the application defined by disk 703. These channels would be filled to accommodate the new application, conduit by conduit, until the recipient channels were filled. Then additional channels (if available) would be transferred to the service requiring additional capacity.

Efficient Packing of Spectrum Into Slots For Selective Assignment

The graph in FIG. 8 depicts a frequency spectrum divided into channels and conduits. A band of frequency which in this particular example is chosen to be 198 MHz and is shown divided into a number of contiguous frequency channels 801-1 to 801-N. One of the channels 801-X is shown in an exploded view to comprise several conduits 802-1 to 802-M which are smaller frequency bands dividing a channel. The frequency band of each channel 801 in the illustrative embodiment is either six or ten MHz. Since the bandwidth demands of different services vary, conduits may be dynamically altered in size (i.e., bandwidth) to match the requirements of the various services they support. In some instances a single conduit will suffice whereas in others several conduits may be assigned to a service. The optimum number of conduits assigned to a service is determined by the demand for that service.

Each channel is assigned to a specific service class at any given time. Services within a service class can share access to the channels assigned to that service class (i.e., use any of the conduits of that channel) on an unprovisioned (i.e., not preallocated) dynamic basis. In the allocation scheme a channel is comprised of several conduits and a conduit is the physical or logical partitioning of a channel. A conduit is the basic unit to provide service to any service class. In the IVOD and IBV service classes, the wireless modulation schema is TDM time slots corresponding to a physical partitioning of spectrum. For narrowband service classes, CDMA is the wireless modulation schema in which individual conduits are in effect logical parts of the overall channel. In each instance, a service assignment is handled by conduits wherein each conduit is assigned to serving a user of a program.

Optimizing Assignment Based on Program Content Requirements

A division of spectrum of channels into high (921-1, 921-2, 92 1-H), medium (911-1, 911-2, 911-M) and low (901-1, 901-2, 901-L) bit rate applications for video services is illustrated in the FIG. 9. The video content is encoded using the emerging MPEG (motion picture expert group) II standard, that operates over a broad range of encoding rates (aproximately 1.544–9 Mbps). Different program content is encoded optimally at different rates (e.g., movies at lower rates, sports at higher rates). Decoding MPEG II sources at variables rates is automatically handled in the MPEG II standard. Some channels are allocated for lower rate encoding, some for medium rate encoding and some for higher rate encoding. The number of channels assigned to each of these program types is based on the program mix required at that time. Such allocations can be preset for static allocation based on time of day and day of week or for dynamic allocation on a real time basis as program content changes are required without prior arrangement. Video programs may be groomed (i.e., channeled) to appropriate channels based on bandwidth requirements. As video programs are reassigned to different channels and conduits (i.e. channel x and conduit y) that information is conveyed to the access director by the IMP. In one illustrative embodiment it is conveyed as a mapping table.

Within a bit rate video service type, programs are encoded at variable rates (within a narrow range around the base average rate specified for the channel based on the program content requirements (e.g., based on the amount of motion in the video picture) in a manner that balances bit rate assignments across all the programs within that channel (e.g., in the 3 Mbps video channel type, one program may be given 2.7 Mbps and another one 3.3 Mbps at one time, and perhaps reversed later, keeping the average across programs to 3 Mbps at all times). To facilitate such an approach, a packetized scheme (i.e., ATM or another packet arrangement) is used because of its inherent bandwidth on demand capability.

The benefit of assigning programs in this manner i.e., higher rates for some programs and simultaneously lower rates for others by both techniques described here, viz; by grooming techniques according to encoding rate requirements and variable rate coding within the same encoding rate levels, is that this ensures a uniform and a more manageable program quality across the channels while simultaneously maximizing utilization of spectrum across the channels.

Definitions of Terms

The following definitions define terms used in the above specification:

Channel: A block of continuous spectrum assigned to a particular class of service. A channel is comprised of a plurality of conduits.

Conduit: Subportion of a channel assigned to a single user or program, for one direction of a duplex communication. More than one conduit may be combined to provide a wider band unidirectional transmission.

Sub-Channel A set of channels assigned to video services belonging to a particular rate of encoding (i.e., low, medium and high).

Interactive Broadcast Video (IBV) (TDM): This service is comprised of two parts: 1. Scheduled video content provided on a broadband (i.e., 1.5 Mbps to 6 Mbps) broadcast downlink basis potentially to all users 2. A narrowband uplink signal (<2.4 Kbps, via wireless data signaling or ISDN D channel) for service request, payment authorization, etc. IBV is provided to support services such as wireless CATV, Enhanced Pay-per-View, electronic shopping, electronic software distribution, instructional and educational

television, multimedia video based information services, etc. IBV uses TDM transmission.

Interactive Video-On-Demand (IVOD) (TDM): IVOD is comprised of two parts: 1. Demand based video content transmitted on the downlink by broadband means (1.5 Mbps to 6 Mbps) only to users requesting to view that content; 2. A moderate speed uplink (<64 Kbps, via ISDN B channel or voice telephony) for service requests, payment authorization, etc. IVOD supports applications such as Video-On-Demand, networked games, interactive distance learning, telemedicine, interactive TV, multimedia video based information services etc. IVOD uses TDM transmission.

Wireless Multimedia: Wideband services at 384 Kbps (bonded 6B channels or ISDN H0 rate) supporting two-way symmetric services. Transmission is implemented by either TDM of CDMA.

Wireless Data: Supports two-way symmetric/asymmetric services (messaging, data and signaling applications up to 19.2 kbps including 0B+D service). Transmission is implemented via CDMA.

Wireless ISDN: A range of Basic rate compatible ISDN services at speeds up to 144 Kbps (1B+D to 2B+D) supporting two way symmetric services. Transmission is implemented via CDMA.

Wireless Basic Voice Telephony (CDMA) Voice service at 32, or 64, or 128 Kbps supporting two way symmetric services (including 1B and 2B services and enhanced high fidelity stereo). Transmission is implemented via CDMA.

Service Class: A portfolio of services using the same air interface that automatically lend themselves to sharing a common bandwidth within a channel across the extent of the portfolio. In our illustrative embodiment three sample service classes are defined.

1. Narrowband service class: This supports services such as basic rate ISDN, and compatible services including 0B+D, 1B+D, 2B, etc. It additionally supports all basic voice telephony (32 Kbps, 64 Kbps) and wireless data.

2. IVOD (see above)

3. IBV (see above)

We claim:

1. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system;

comprising the steps of:

coupling end user equipment to the communication system by wireless transmission media utilizing a combination of spread spectrum and time division multiplex transmission to an access antenna;

at the end user premises re-transmitting a down link spread spectrum and time division transmission from the access antenna and transmitting up link spread spectrum and time division transmission to the access antenna;

partitioning available spectrum into specific channel/conduit components aligned to specific services to the end user and allocating sub channels and conduits to provide needed bandwidth for a particular application by the steps of defining asymmetrical broadband channels and bidirectional symmetrical narrowband channels by assigning channels into specific service categories; and

subdividing the channels into conduits of specified bandwidth each of which may be combined to be assigned to a specific service.

2. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system, as claimed in claim 1,

wherein the step of partitioning further includes the step of selecting conduits within channels to match bandwidth requirements of services to be provided.

3. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system, as claimed in claim 2,

wherein the step of partitioning further includes the step of mapping of a single service onto several conduits selected to match bandwidth requirements of that single service.

4. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system, as claimed in claim 3,

wherein conduits are assigned based on modulation requirements of a service by selecting CDMA modulation for narrowband and TDM for broadband service.

5. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system, as claimed in claim 4,

wherein channels are assigned to service classes to match static and variability in demand.

6. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system, as claimed in claim 5,

wherein a channel is encoded by a modulation schema by utilizing CDMA for optimizing narrow band frequency reuse; and

optimizing broadband applications by means of compression and by using TDM schema.

7. In a wireless broadband communication system, a method of delivering a variety of broadband/narrowband services to an end user of the system, as claimed in claim 6,

maximizing channel utilization while providing uniform service quality by varying conduit bit rate to match program requirements while maintaining an average bit rate for all conduits in a channel.

8. In a communication network for providing broadband and narrowband services with a wireless connection between the network and end users; a method of allocating frequency spectrum to satisfy service bandwidth requirements of a plurality of services;

comprising the steps of:

periodically setting a re-allocation time;

static allocating of channels to meet service demand on a known predetermined allocation basis supported by time and date records at a periodic reallocation time to meet anticipated demand at that time and date;

dynamic allocating of channels to meet service demand on immediate service requests in real time by determining an idle capacity of channels, measuring a number of channels assigned to incumbent service classes, determining if a number of idle channels exceeds the channels assigned to incumbent service classes by a block number, determining channels to be assigned to a different service class; and

the dynamic allocating having precedence over the static allocating.

9. In a communication network for providing broadband and narrowband services with a wireless connection between the network and end users, a method of allocating frequency spectrum to satisfy service bandwidth requirements of a plurality of services, as claimed in claim 8:

determining if there is blocking on channels to be assigned to a different service class; and

reassigning unused channels to a different service class.

10. In a communication network for providing broadband and narrowband services with a wireless connection between the network and end users, a method of allocating frequency spectrum to satisfy service bandwidth requirements of a plurality of services, as claimed in claim 9:

establishing a waiting period before a subsequent dynamic allocation.

11. In a communication network for providing broadband and narrowband services with a wireless connection between the network and end users, a method of allocating frequency spectrum to satisfy service bandwidth requirements of a plurality of services, as claimed in claim 9:

reallocations of channels from one service class to another service class are in incremental integer numbers of channels.

12. In a communication network for providing broadband and narrowband services with a wireless connection between the network and end users; a method of allocating frequency spectrum in both spread spectrum and TDM transmissions to satisfy service bandwidth requirements in providing end users with a plurality of services;

comprising the steps of:

periodically setting a re-allocation time;

statically allocating channels to meet service demand on a known predetermined allocation basis supported by time and date records at the reallocation time;

dynamically allocating channels to meet service demand on immediate service requests in real time; statically and dynamically allocating channels by partitioning of the available frequency spectrum, and

the dynamic allocating having precedence over the static allocating.

13. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, comprising:

an asynchronous transport mode network and a synchronous transport mode network;

a service node connected to the asynchronous transport mode network and the synchronous transport mode network and an access node which is in turn connected to a microport including an antenna for radiating radio signals to a receiving antenna of an end user;

a channel allocation server, connected to the service node, for estimating blocking probabilities across service chases and for identifying channels to be moved from one service class to another to accommodate service demands;

communication circuitry for communicating and for providing communication network routing control;

wherein the communication network apportions communication channels and conduits to specific communication services;

and wherein the service node measures channel occupancy of the channels controlled by the communication system and assigns network trunks to operate as access trunks;

the access node combining and splitting channels to conform with the mapping of services onto channels;

the microport having radiant apparatus to transmit and receive signals over air media and associating wired channels of the networks to a RF channel; and

the access port connecting received wireless signals to wired and wireless equipment of the end user and transmitting wireless signals from the end user to the microport.

14. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, comprising:

a signaling server for providing signaling services to end user devices.

15. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, comprising:

a billing operations, administration, maintenance and provision server for providing integrated billing across all broadband and narrowband services to end users.

16. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, comprising:

a security server for providing security authentication and fraud prevention services.

17. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, comprising:

a customer profile server for storing end user data including subscriber preferences.

18. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, comprising:

a user registration server for maintaining real time data concerning a users location and service area related data.

19. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, comprising:

a signaling server, an Interactive Video On Demand (IVOD) server, a security server, a billing operations, administration, maintenance and provision server server, a customer service profile server and a location and user registration server, and a channel allocation server; all integrated within the system to provide integrated service across end-to-end of the network to end users across an entire portfolio of services.

20. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, further comprising:

the access node dividing channels into a fixed plurality of conduits, the plurality of conduits each being variable in bandwidth, with the plurality of conduits having a fixed overall bandwidth and the average bandwidth of the each conduit of the plurality of conduits remaining fixed.

21. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 13, further comprising:

a radiant apparatus comprises a sectored antenna with three sectors and radiating three levels of channels for interactive broadcast video services, interactive video on demand services and narrowband services; and

the channel allocation server controlling transfers of channel assignments from one level to another.

22. A communication network for providing broadband and narrowband services with a wireless connection

between the network and end users, as claimed in claim 20 or 21, further comprising:

the access node being connected to the service node with a SONET ring.

23. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 22, further comprising:

antenna means for accepting satellite signals to support broadcast video, multimedia, and information services.

24. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users as claimed in claim 20 or 21, further comprising:

the access node being connected to the service node with a point-to-point microwave connection.

25. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 20 or 21, further comprising:

the access node being connected to the service node with a point-to-point infrared connection.

26. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 20 or 21, further comprising:

the access node being connected to the service node with a star connection.

27. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users as claimed in claim 20 or 21, further comprising:

the access node extending available services by adding interactive services by providing interactive uplink channels.

28. A communication network for providing broadband and narrowband services with a wireless connection between the network and end users, as claimed in claim 20 or 21, further comprising:

the access node adding new services by utilizing compression techniques to pack existing services into a subset of channels to free channels for new services.

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US005604730A

United States Patent [19]

Tiedemann, Jr.

[11] **Patent Number: 5,604,730**

[45] **Date of Patent: Feb. 18, 1997**

[54] **REMOTE TRANSMITTER POWER CONTROL IN A CONTENTION BASED MULTIPLE ACCESS SYSTEM**

[75] Inventor: **Edward G. Tiedemann, Jr.**, San Diego, Calif.

[73] Assignee: **QUALCOMM Incorporated**, San Diego, Calif.

[21] Appl. No.: **280,095**

[22] Filed: **Jul. 25, 1994**

[51] **Int. Cl.**^{6} **H04J 3/14**

[52] **U.S. Cl.** **370/252**; 455/69; 370/335

[58] **Field of Search** 370/18, 13, 17, 370/95.1, 95.2, 95.3, 110.1, 77; 455/38.3, 69, 70, 92, 68, 95; 375/200, 205, 206, 208; 340/825.08

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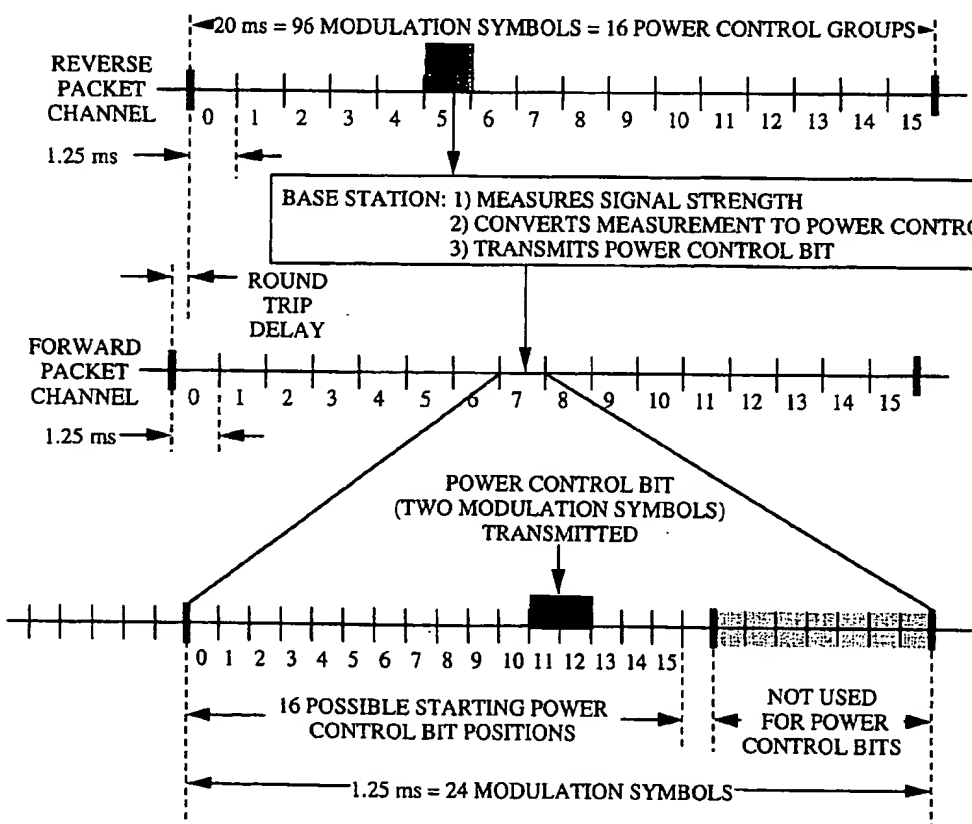
Primary Examiner—Wellington Chin
Assistant Examiner—Huy D. Vu
Attorney, Agent, or Firm—Russell B. Miller; Roger W. Martin

[57] **ABSTRACT**

The power control process of the present invention enables a base station communicating over a forward packet channel to a mobile radio to control the power of the mobile radio transmitting over a reverse packet channel to the base station. The base station maintains a maximum energy per bit to total interference spectral density ratio threshold for the reverse channel as well as a desired threshold that results in a low frame error rate. By comparing each radiotelephone's estimated energy per bit to total interference spectral density ratio to the desired and maximum thresholds, power control commands to increase or decrease the radiotelephone's transmit power are generated depending on the outcome of the comparison.

29 Claims, 10 Drawing Sheets



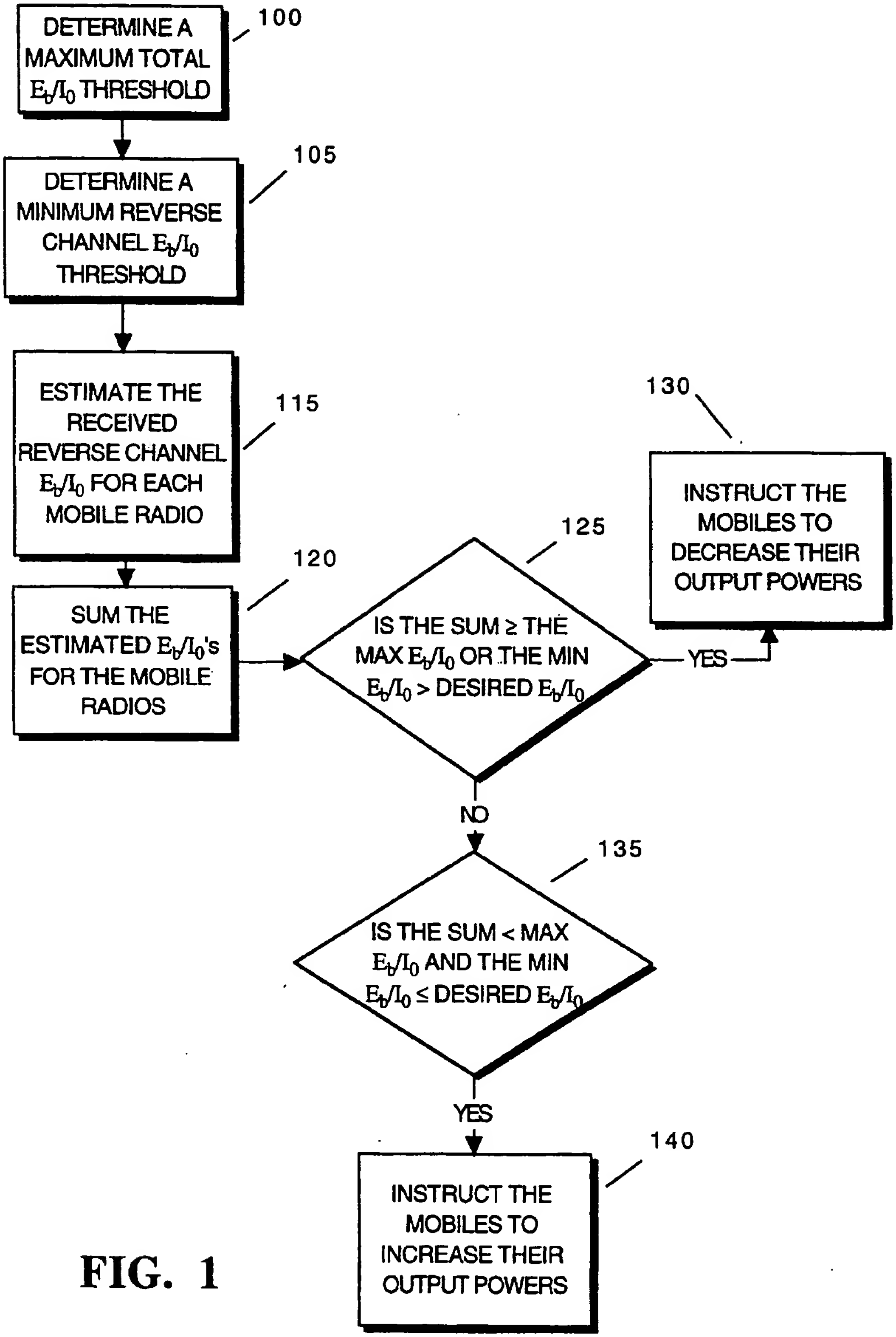

DETERMINE A MAXIMUM TOTAL E_b/I_0 THRESHOLD
100
DETERMINE A MINIMUM REVERSE CHANNEL E_b/I_0 THRESHOLD
105
ESTIMATE THE RECEIVED REVERSE CHANNEL E_b/I_0 FOR EACH MOBILE RADIO
115
SUM THE ESTIMATED E_b/I_0's FOR THE MOBILE RADIOS
120
IS THE SUM ≥ THE MAX E_b/I_0 OR THE MIN E_b/I_0 > DESIRED E_b/I_0
125
YES
INSTRUCT THE MOBILES TO DECREASE THEIR OUTPUT POWERS
130
NO
IS THE SUM < MAX E_b/I_0 AND THE MIN E_b/I_0 ≤ DESIRED E_b/I_0
135
YES
INSTRUCT THE MOBILES TO INCREASE THEIR OUTPUT POWERS
140

FIG. 1

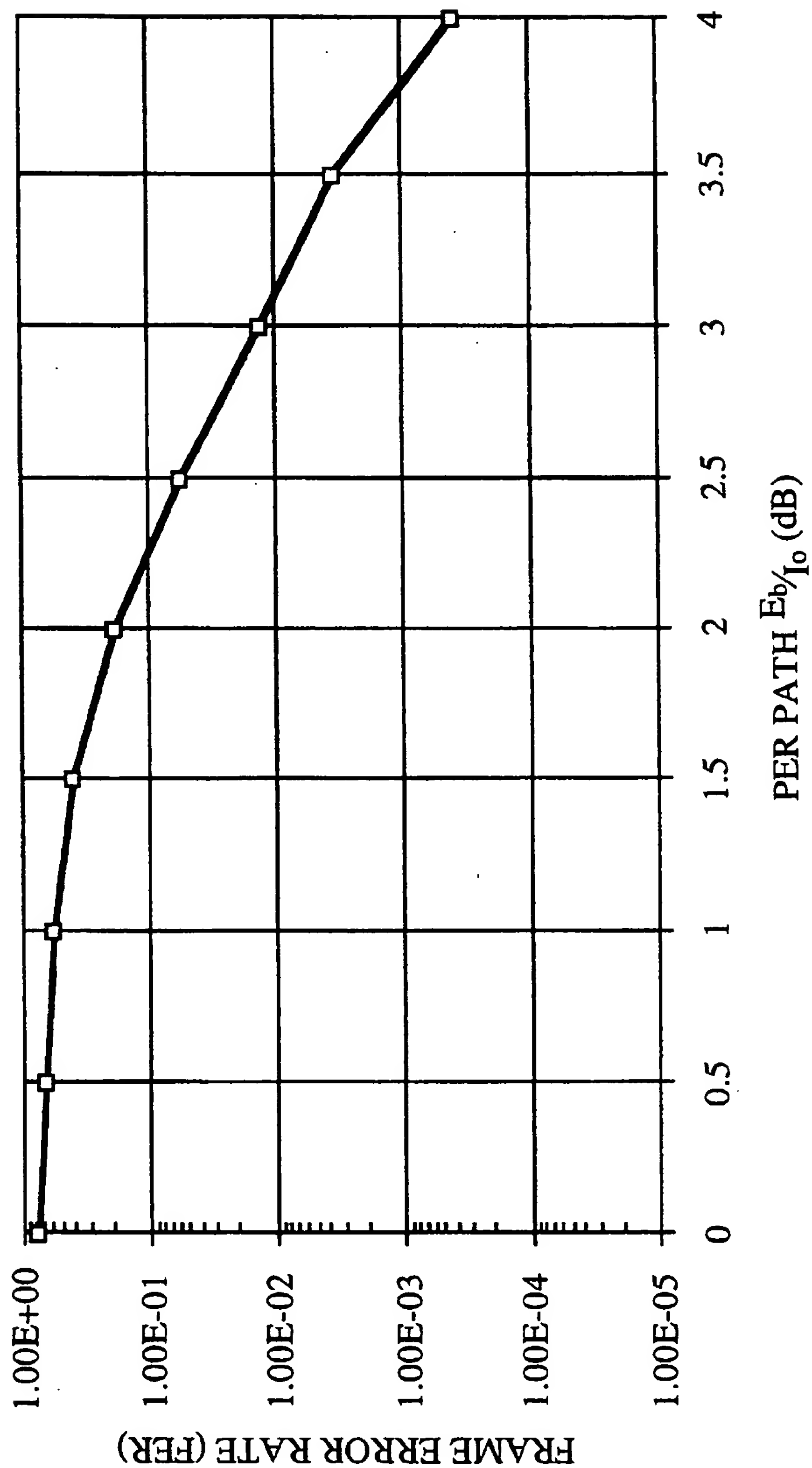

1.00E+00
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
FRAME ERROR RATE (FER)
0
0.5
1
1.5
2
2.5
3
3.5
4
PER PATH E_b/I_o (dB)

FIG. 2

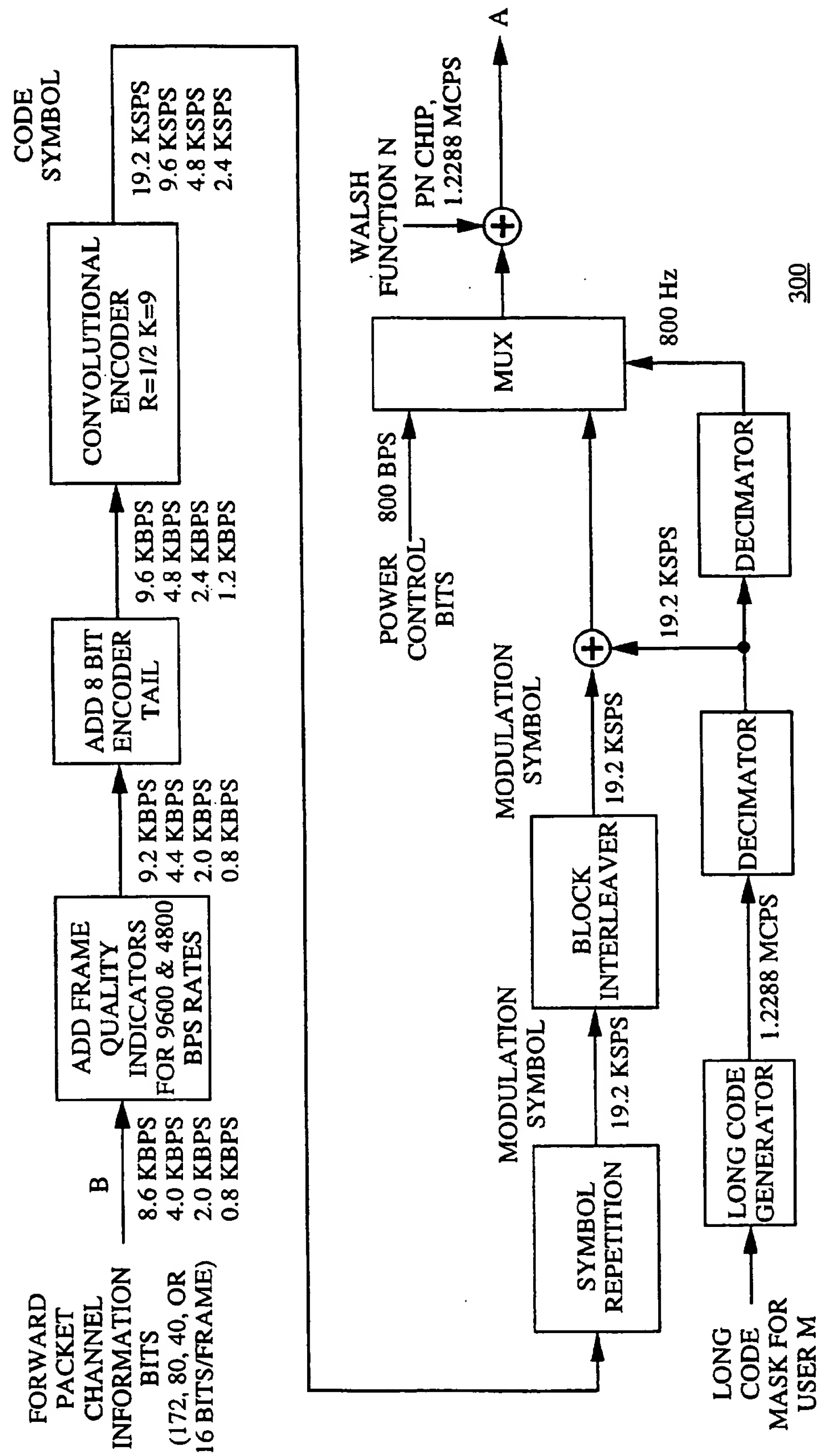

FORWARD PACKET CHANNEL INFORMATION BITS (172, 80, 40, OR 16 BITS/FRAME)
B
8.6 KBPS
4.0 KBPS
2.0 KBPS
0.8 KBPS
ADD FRAME QUALITY INDICATORS FOR 9600 & 4800 BPS RATES
9.2 KBPS
4.4 KBPS
2.0 KBPS
0.8 KBPS
ADD 8 BIT ENCODER TAIL
9.6 KBPS
4.8 KBPS
2.4 KBPS
1.2 KBPS
CONVOLUTIONAL ENCODER R=1/2 K=9
CODE SYMBOL
19.2 KSPS
9.6 KSPS
4.8 KSPS
2.4 KSPS
SYMBOL REPETITION
MODULATION SYMBOL
19.2 KSPS
BLOCK INTERLEAVER
MODULATION SYMBOL
19.2 KSPS
POWER CONTROL BITS
800 BPS
MUX
WALSH FUNCTION N
PN CHIP, 1.2288 MCPS
A
800 Hz
19.2 KSPS
DECIMATOR
DECIMATOR
1.2288 MCPS
LONG CODE GENERATOR
LONG CODE MASK FOR USER M
300

FIG. 3a

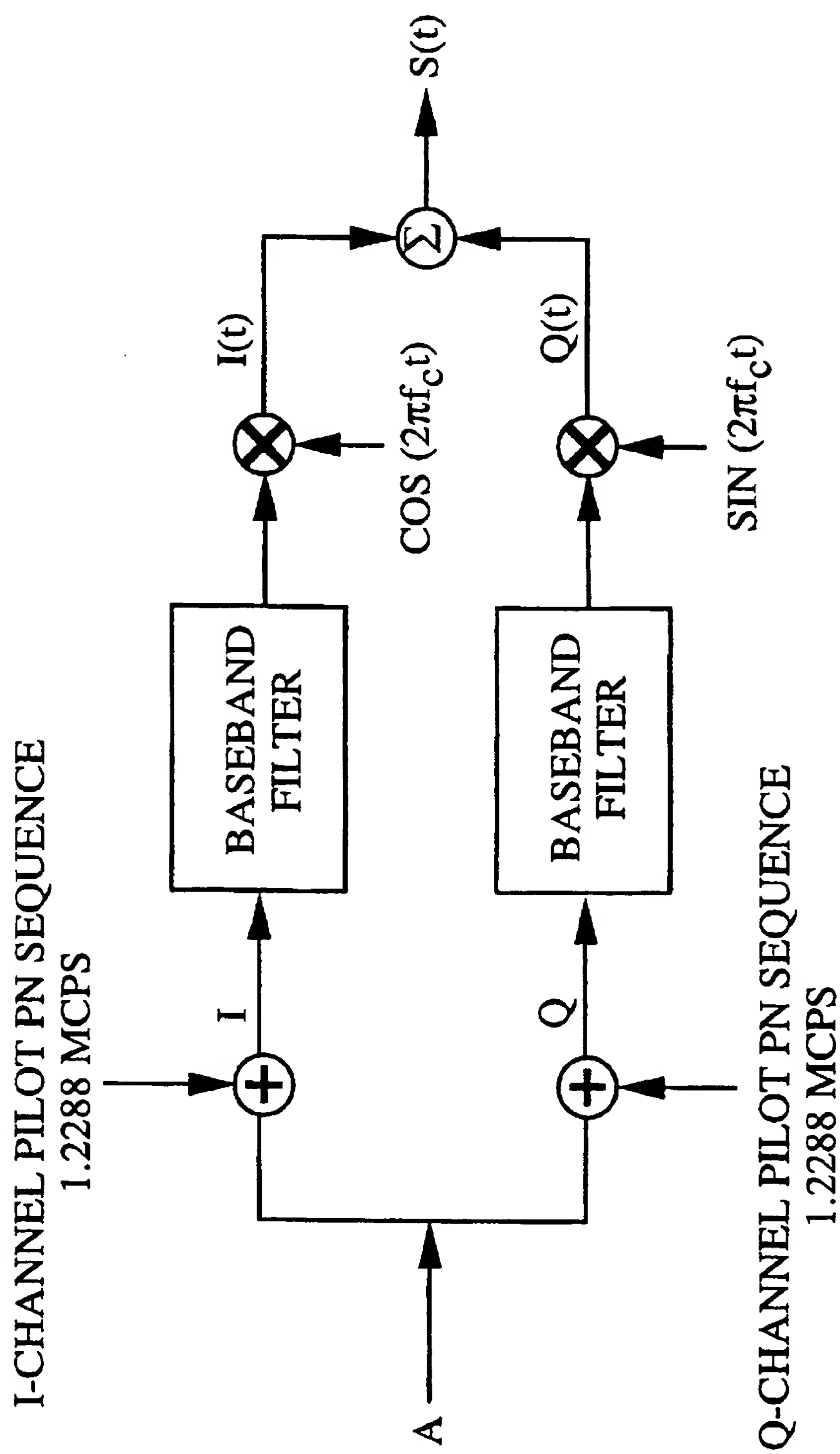
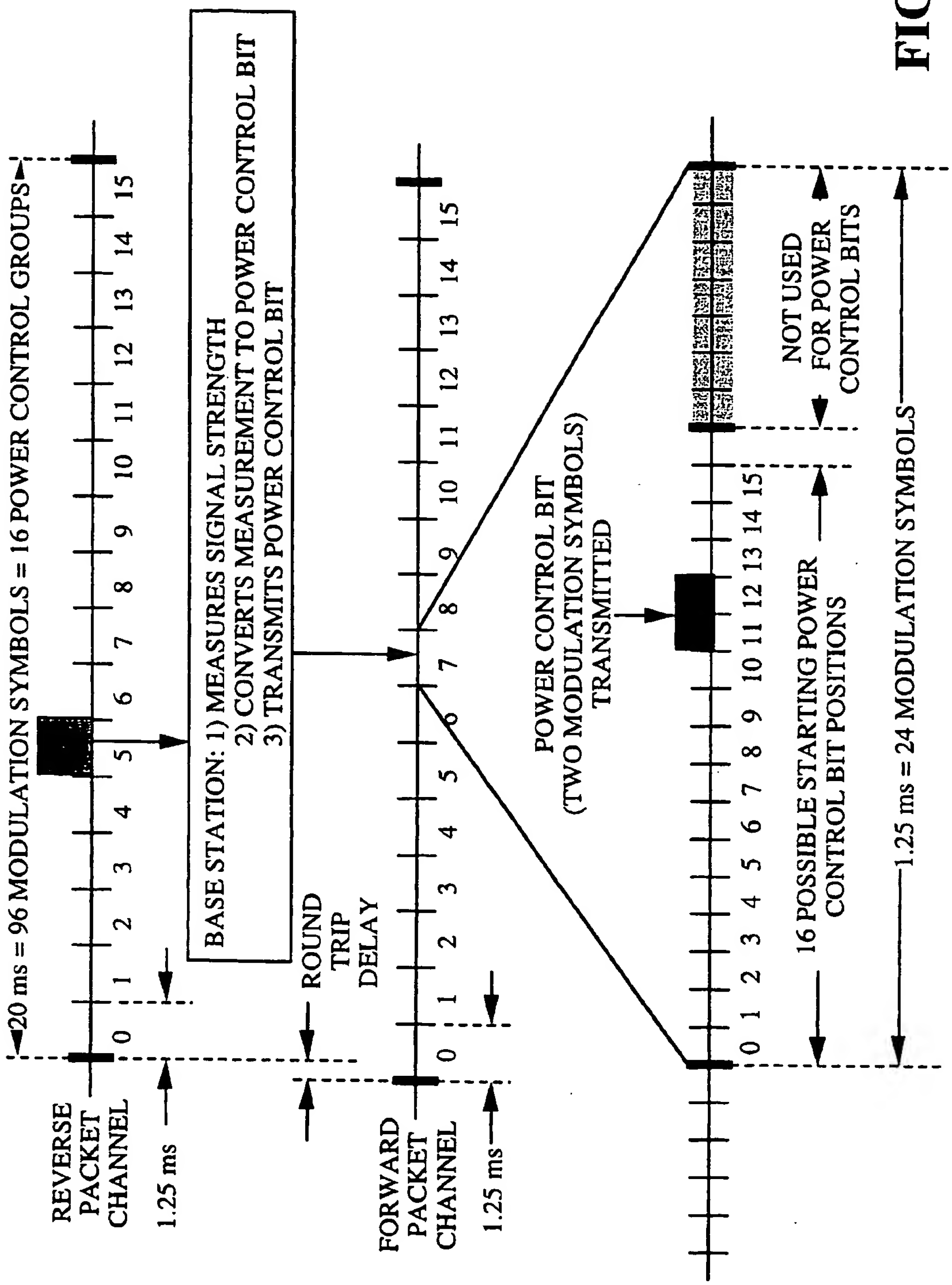

S(t)
Σ
I(t)
Q(t)
COS $(2\pi f_c t)$
SIN $(2\pi f_c t)$
BASEBAND FILTER
BASEBAND FILTER
I
Q
I-CHANNEL PILOT PN SEQUENCE
1.2288 MCPS
Q-CHANNEL PILOT PN SEQUENCE
1.2288 MCPS
A

FIG. 3b

FIG. 4


20 ms = 96 MODULATION SYMBOLS = 16 POWER CONTROL GROUPS
REVERSE PACKET CHANNEL
1.25 ms
BASE STATION: 1) MEASURES SIGNAL STRENGTH
2) CONVERTS MEASUREMENT TO POWER CONTROL BIT
3) TRANSMITS POWER CONTROL BIT
ROUND TRIP DELAY
FORWARD PACKET CHANNEL
1.25 ms
POWER CONTROL BIT
(TWO MODULATION SYMBOLS)
TRANSMITTED
NOT USED FOR POWER CONTROL BITS
16 POSSIBLE STARTING POWER CONTROL BIT POSITIONS
1.25 ms = 24 MODULATION SYMBOLS

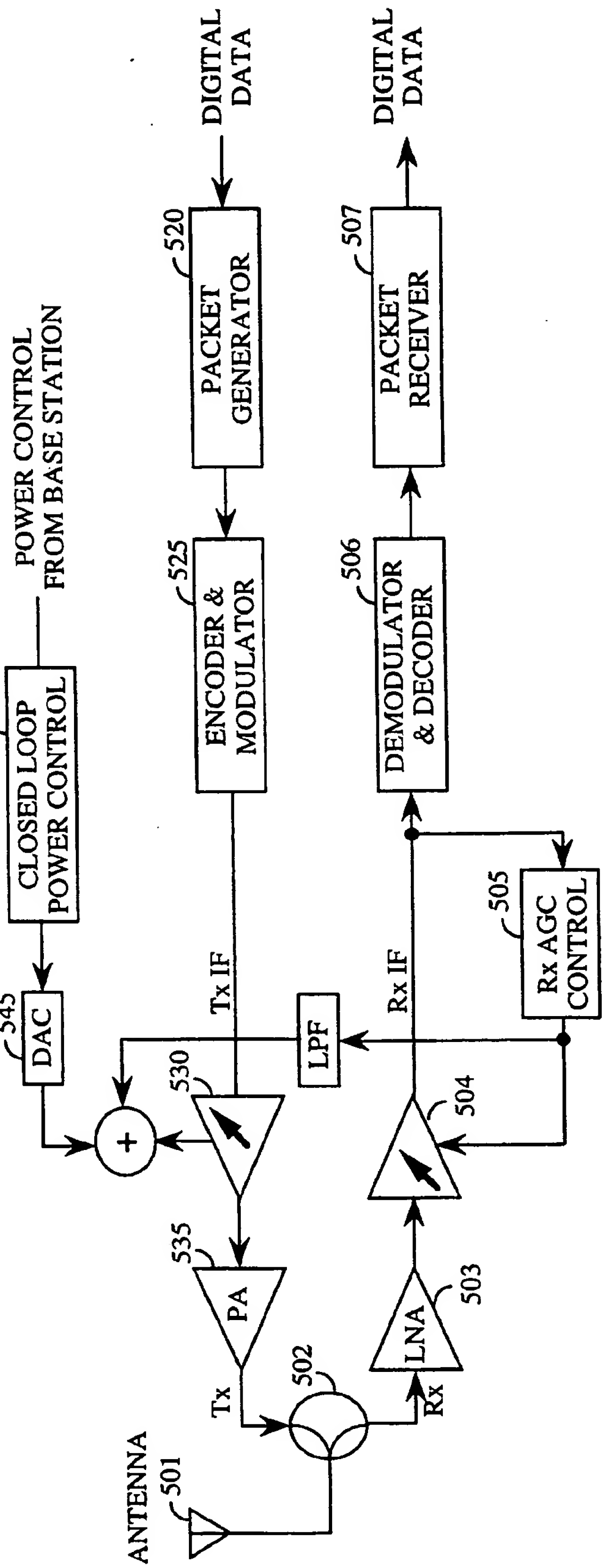
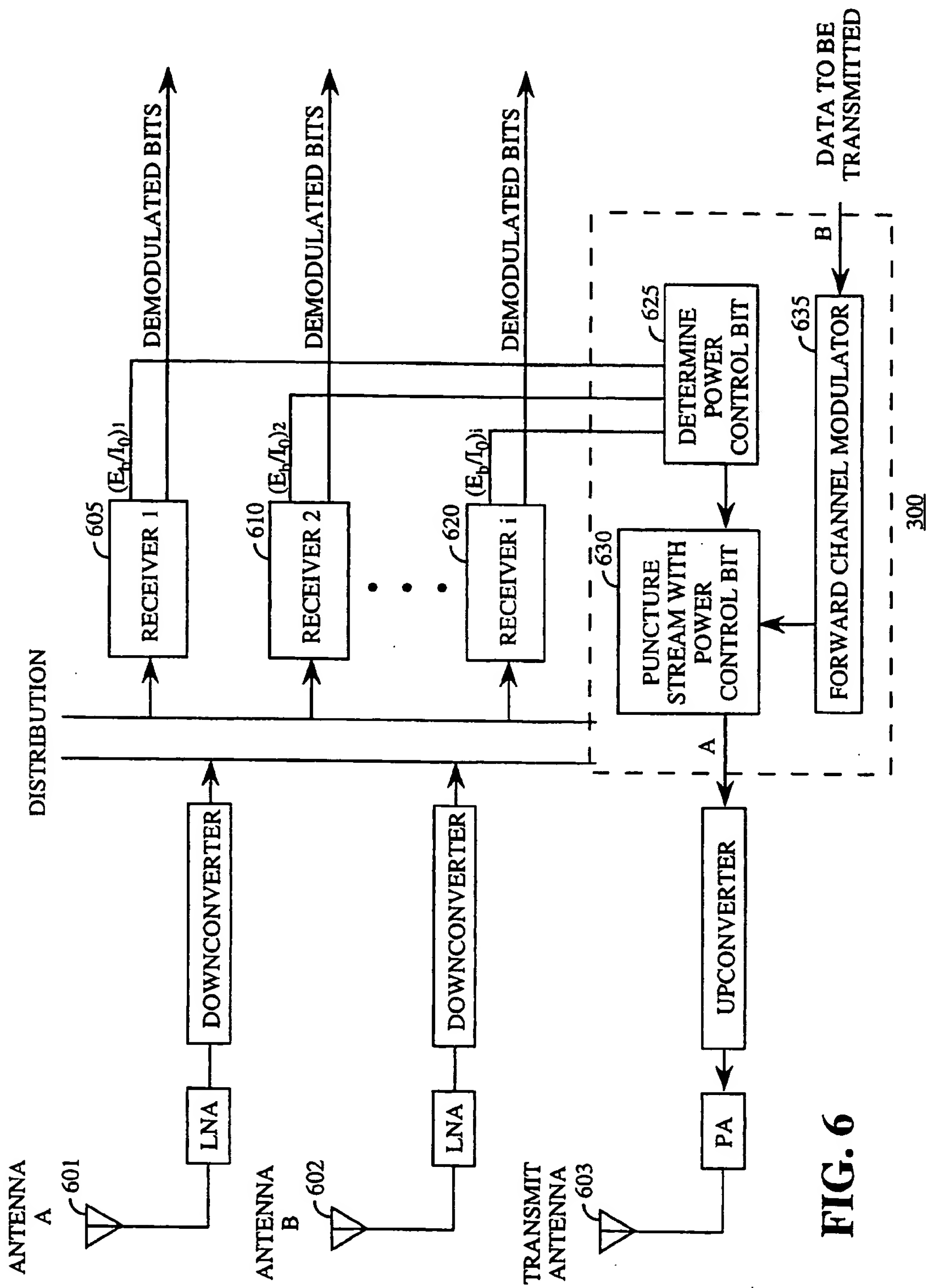

DIGITAL DATA
DIGITAL DATA
POWER CONTROL FROM BASE STATION
520
PACKET GENERATOR
507
PACKET RECEIVER
525
ENCODER & MODULATOR
506
DEMODULATOR & DECODER
540
CLOSED LOOP POWER CONTROL
505
Rx AGC CONTROL
545
DAC
Tx IF
Rx IF
LPF
530
504
535
PA
503
LNA
502
Tx
Rx
ANTENNA
501

FIG. 5



ANTENNA A
601
LNA
DOWNCONVERTER
ANTENNA B
602
LNA
DOWNCONVERTER
TRANSMIT ANTENNA
603
PA
UPCONVERTER
DISTRIBUTION
605
RECEIVER 1
610
RECEIVER 2
620
RECEIVER i
$(E_b/I_0)_1$
$(E_b/I_0)_2$
$(E_b/I_0)_i$
DEMODULATED BITS
DEMODULATED BITS
DEMODULATED BITS
625
DETERMINE POWER CONTROL BIT
630
PUNCTURE STREAM WITH POWER CONTROL BIT
635
FORWARD CHANNEL MODULATOR
DATA TO BE TRANSMITTED
A
B
300

FIG. 6

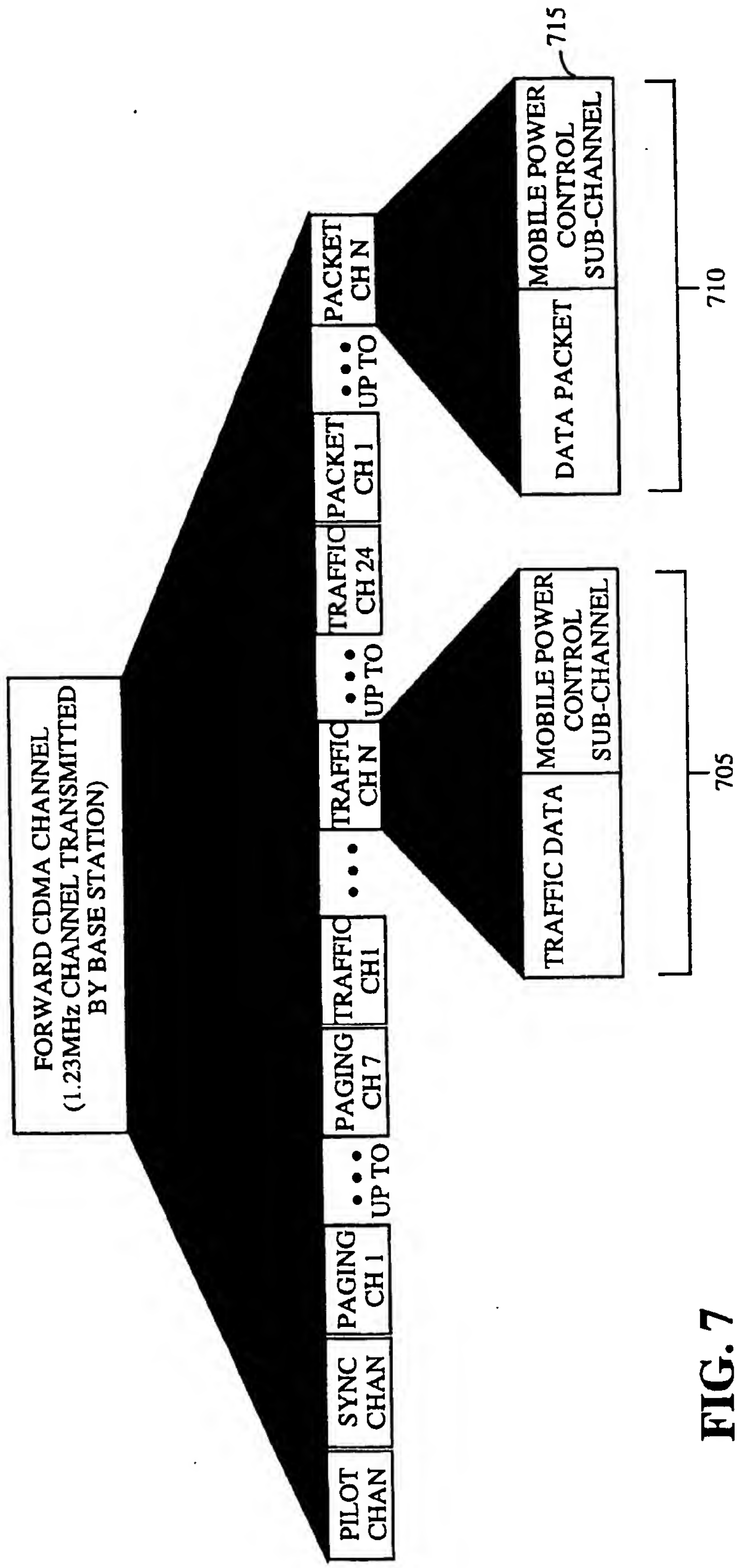

FORWARD CDMA CHANNEL
(1.23MHz CHANNEL TRANSMITTED
BY BASE STATION)
PILOT CHAN
SYNC CHAN
PAGING CH 1
UP TO
PAGING CH 7
TRAFFIC CH1
TRAFFIC CH N
UP TO
TRAFFIC CH 24
PACKET CH 1
UP TO
PACKET CH N
TRAFFIC DATA
MOBILE POWER CONTROL SUB-CHANNEL
705
DATA PACKET
MOBILE POWER CONTROL SUB-CHANNEL
710
715

FIG. 7

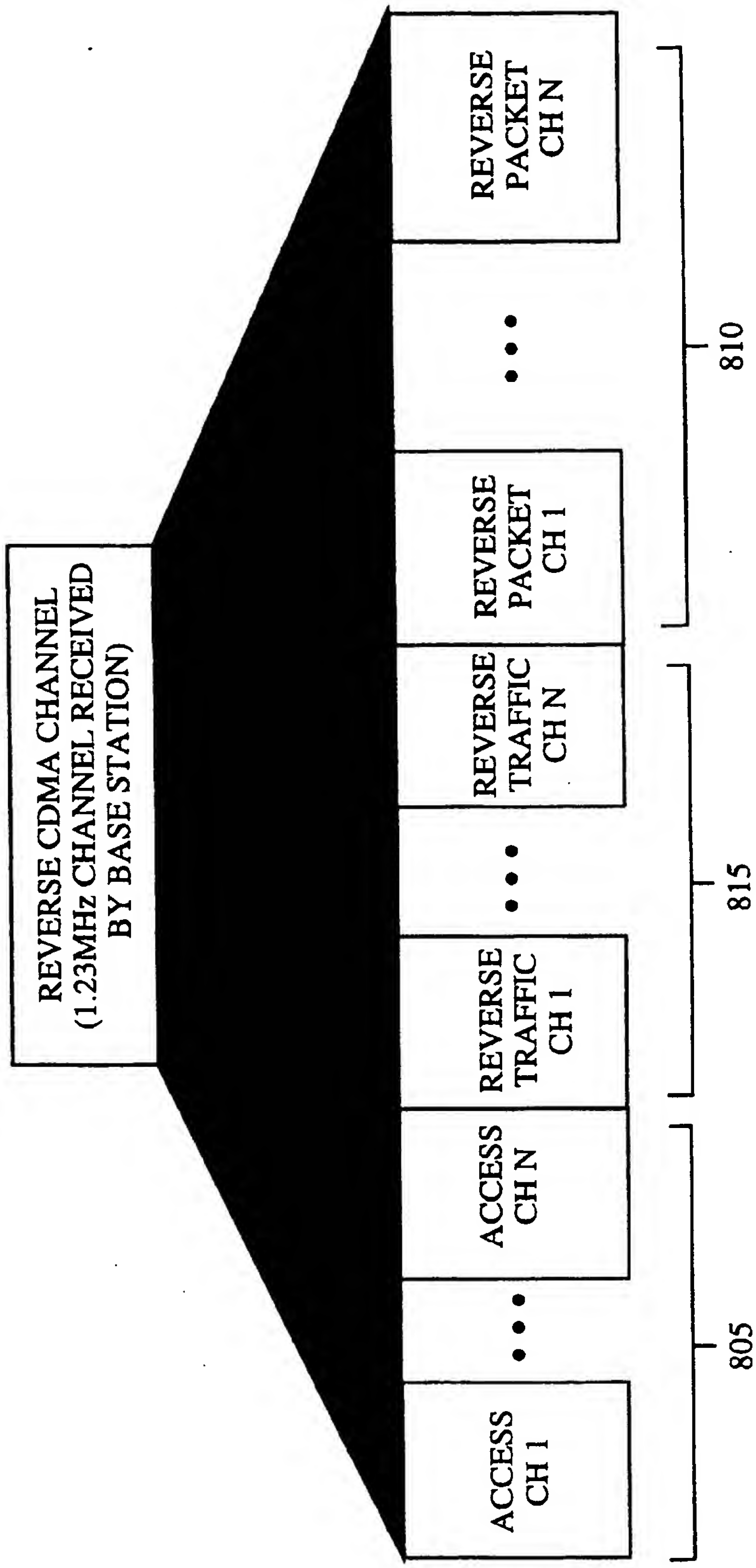
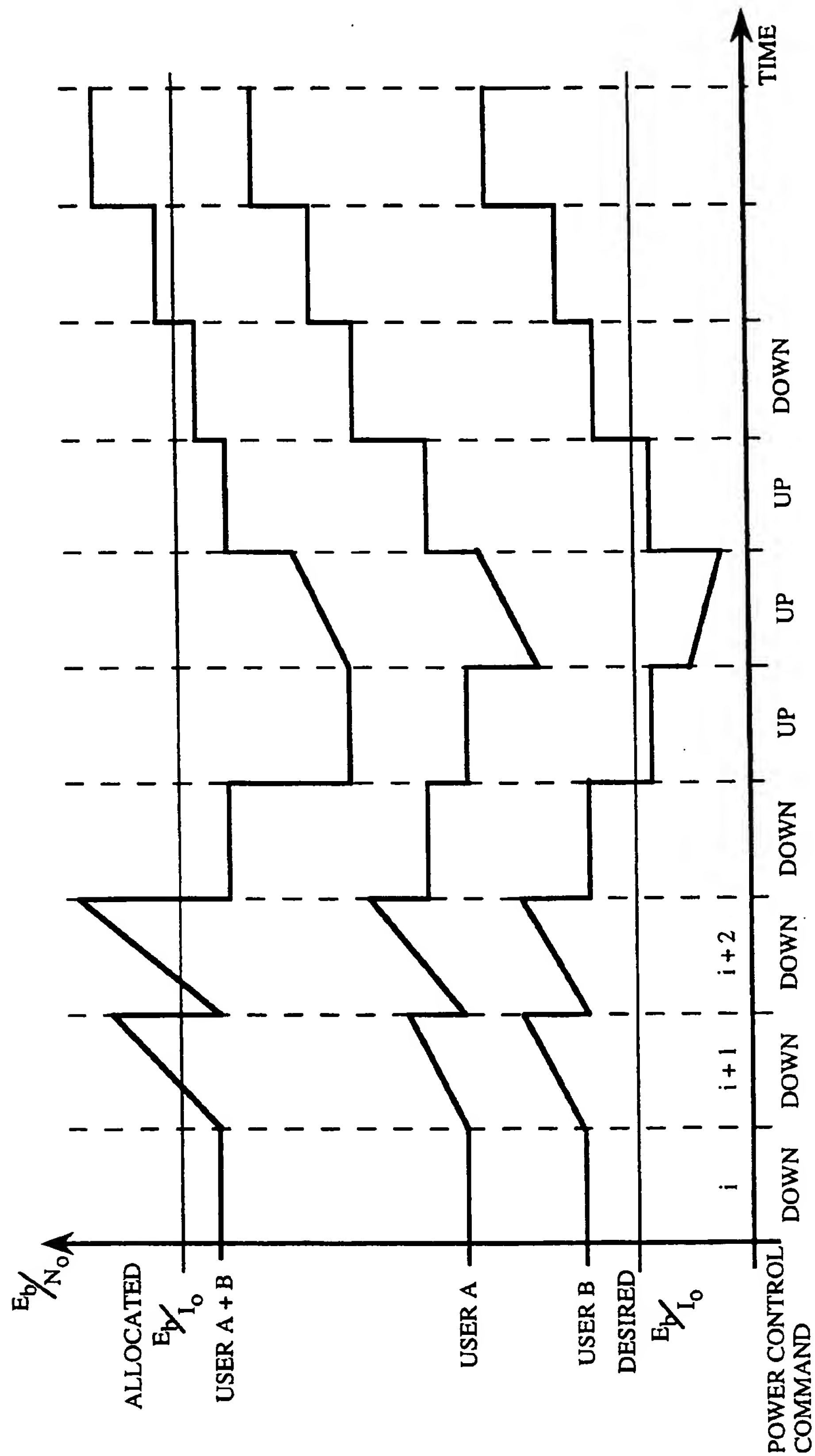

REVERSE CDMA CHANNEL
(1.23MHz CHANNEL RECEIVED
BY BASE STATION)
ACCESS
CH 1
ACCESS
CH N
REVERSE
TRAFFIC
CH 1
REVERSE
TRAFFIC
CH N
REVERSE
PACKET
CH 1
REVERSE
PACKET
CH N
805
815
810

FIG. 8



TIME
DOWN
UP
UP
UP
DOWN
DOWN
i + 2
DOWN
i + 1
DOWN
i
DOWN
Eb/No
ALLOCATED
Eb/Io
USER A + B
USER A
USER B
DESIRED
Eb/Io
POWER CONTROL
COMMAND

FIG. 9

REMOTE TRANSMITTER POWER CONTROL IN A CONTENTION BASED MULTIPLE ACCESS SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to wireless communications. More particularly, the present invention relates to power control in a CDMA communication system.

2. Description of the Related Art

A packet is one method of packaging user data. Typically, the packet is divided up into various fields, with each field comprising one or more bits. Each field is used for a predetermined function such as user data, addresses, error detection, etc. Data packets can be formed according to pre-existing protocols such as X.25 and TCP/IP that are well known in the art.

Packets may be used with a true packet service in which the application, transport, or other layer generates the packet. Packets can also be generated by a network's lower protocol layer that breaks a stream of data bits into data packets of predetermined length.

Data packets can be transmitted over a radio channel using many methods. A first method uses a dedicated channel to carry packets between a pair of radio transceivers. A second method encompasses a single, central radio transceiver that transmits over a common channel to one or more other radio transceivers that are monitoring for packets containing data in the address field signifying that radio transceiver's particular address. A third method uses a random access or contention based protocol in which the packets are transmitted from one or more radio transceivers to either a central terminal or each other.

In a typical CDMA cellular communication system that follows the Telecommunications Industries Association/Electronic Industries Association Interim Standard 95 (TIA/EIA/IS-95), the dedicated channel corresponds to a traffic channel. This channel transmits voice and data signals between the mobile radio and the base station. The common channel approach corresponds to transmitting on the paging channel that is used to broadcast pages in a CDMA system when each page carries an address. The random access approach corresponds to the access channel. A typical CDMA-type communication system is described in greater detail in U.S. Pat. No. 5,103,459 to Gilhousen et al. and assigned to Qualcomm, Inc.

When one or more packets are to be transmitted between a base station and mobile radio or vice versa, a traffic channel can be allocated between the two. Once a packet is transmitted, the time to the next packet is often unknown. Instead of having the traffic channel allocated and unused, the channel is deallocated after a period of idleness. This period can be fixed with the period determined by analyzing typical traffic patterns. Alternatively, this period can also be variable with the period set by analyzing the transmitted packet stream.

The allocation of traffic channels presents at least two problems. First, the traffic channel takes time to set up, thus delaying the packet transmission. In some instances, setting up a traffic channel could require more than a second. Second, the resources to set up and use a traffic channel may be too expensive to justify the transmission of infrequent packets, short packets, or short sequences of packets.

Power control in a CDMA system is very important since a large number of mobile radios are transmitting on the same

frequency. If one mobile is transmitting at a power output that is too large, it can degrade the received $^{Eb}/_{Io}$ from other mobile radios to the point that the base station cannot correctly demodulate transmissions. If the mobile radio transmits at too low of an output power, the received $^{Eb}/_{Io}$ from the mobile radio at the base station will be too low to properly demodulate the $^{Eb}/_{Io}$ received signal. The mobile radio's transmit power, therefore, has an affect on system capacity.

The correlation between $^{Eb}/_{Io}$ and system capacity can be shown as follows. When there are no mobile radios in other cells, the maximum number of simultaneous transmissions, N, is approximately:

$$N \approx \frac{W/R - (E_b/I_o)_{des}(N_o W/P_r)}{(E_b/I_o)_{des}}$$

where:

W=spreading bandwidth,

R=data rate,

$(^{Eb}/_{Io})_{des}$=desired quality metric subsequently explained in greater detail,

N_0=thermal noise spectral density of the base station receiver, and

P_r=received power per transmission.

The second term in the numerator is typically very small compared to $^{W}/_{R}$, therefore,

$$N \approx \frac{W/R}{(E_b/I_o)_{des}}.$$

Thus, a system using a higher desired $^{Eb}/_{Io}$ lowers capacity.

For the i^{th} mobile radio, the received $^{Eb}/_{Io}$, denoted by $(^{Eb}/_{Io})_i$, at the base station is approximately

$$(E_b/I_o)_i \approx \frac{P_{ri}/R}{\sum_{j \neq i} P_{rj}/W}.$$

The probability that the transmission can be successfully demodulated is high if $(^{Eb}/_{Io})_i$ exceeds $(^{Eb}/_{Io})_{des}$ as is described above. If P_{ri} is large, however, the $^{Eb}/_{Io}$ is degraded for other mobile radios. If the received $^{Eb}/_{Io}$ falls below $(^{Eb}/_{Io})_{des}$, the probability that the transmission will not be successfully demodulated is high.

The mobile radio dynamically adjusts its transmit power using closed and open loop power control in order to maintain the proper received $^{Eb}/_{Io}$ at the base station as channel conditions change or the range to the base station changes. Open loop power control adjusts the mobile radio's transmit power autonomously by measuring the received power on the forward channel. Closed loop power control adjusts the mobile radio's transmit power by a feedback bit stream from the base station. The base station measures the received $^{Eb}/_{Io}$ to determine the feedback bit stream. Closed loop and open loop power control together determine the mobile radio's transmit power, as disclosed in U.S. Pat. No. 5,056,109 to Gilhousen et al. and assigned to Qualcomm, Incorporated.

Closed loop power control compensates for the differences in fading between the forward and reverse links, such as occurs when they are different frequencies. Additionally, it serves to compensate for the differences in transmit and receive path gains in the mobile radio and base station.

Closed loop power control is possible in a typical communication system since there is one traffic channel per mobile radio. This one-to-one channel pairing permits the

base station to measure the mobile radio's reverse channel power and for the mobile radio to utilize the power control bit stream from the base station on the forward channel.

A multi-access channel, however, does not have a one-to-one channel pairing, as multiple mobile radios can transmit simultaneously. The identity of the mobile radio, therefore, is not necessarily known to the base station. Also, the mobile radios do not know the number of mobile radios transmitting, thus the association of the power control bit stream is not clear to the mobile radio.

Since the mobile radio aligns its transmit timing with the timing of the signals that it receives from the base station and all base station signals are time aligned, when two simultaneous transmissions occur on the reverse channel and there is no multipath, the transmissions arrive at the base station separated by times equal to the difference of twice the distances between each mobile radio and the base station. If this time exceeds one pseudo noise chip, the two transmissions can be distinguished by the base station. The inability to distinguish these multipath transmissions is a collision.

When there is multipath, there is no collision if the base station can identify and properly combine the multipath components. If three or more access channel transmissions occur in the same slot, then some transmissions may collide while others do not. In a typical multi-access channel, such as is found in a TDMA or an FDMA system, when two simultaneous transmissions occur there is a collision and neither transmission is successfully demodulated by the base station.

Base stations may further reduce interference with each other by transmitting with the minimum power necessary for their signals to be received by the base station. A mobile radio transmits its first transmission or probe at a power level somewhat less than it estimates to be necessary to reach the base station. This conservative estimate may be a predetermined value or it may be calculated in response to the measured power level of a signal that the mobile radio has or is receiving from the base station.

A preferred embodiment is for the mobile radio to measure the received power from the base station. This received power is the transmitted power of the base station times the path loss. The mobile radio then uses this estimate, plus a constant correction, plus adjustment factors to set the initial transmit power. These adjustment factors may be sent to the mobile radio from the base station. Some of these factors correspond to radiated power of the base station. Since the path loss from the mobile station to the base station is essentially the same as from the base station to the mobile station, the signal received at the base station should be at the correct level, assuming that the base station has supplied the appropriate correction factors and that the mobile radio and base station gains are error free.

After transmitting the first access probe at this minimum power level, the mobile station increases the power of successive probes within each access probe sequence by a predetermined step amount. A thorough discussion of access probes is evident in IS-95, section 6.6.3.1 and in co-pending U.S. patent application, *Apparatus and Method for Reducing Collisions Between Mobile Stations Simultaneously Accessing a Base Station in a CDMA Cellular Communications System*, Ser. No. 08/219,867 to Tiedemann et al. and assigned to Qualcomm, Inc.

In addition, between successive transmissions of an access probe, the mobile radio can randomize its transmission time and choose another access channel so as to avoid a potential collision. IS-95, section 6.6.3.1 describes this in greater detail.

It can be seen, therefore, that power control is very important for proper operation of a CDMA radiotelephone system. There is a resulting need for a power control process in a multiple access system to increase system capacity.

SUMMARY OF THE INVENTION

The power control process of the present invention uses a comparison threshold to determine whether the base station should instruct the mobile radios to increase or decrease their transmit power. The total received $^{Eb}/_{Io}$ for all the mobile radios communicating with a particular base station is compared to a maximum threshold for the reverse channel. Additionally, a minimum comparison threshold for the mobile radio being controlled is determined. If the total received $^{Eb}/_{Io}$ is greater than or equal to the maximum threshold or the minimum received $^{Eb}/_{Io}$ for any mobile radio is greater than the reverse channel minimum, the base station instructs the mobile radios to decrease their output power. If the total received $^{Eb}/_{Io}$ is less than the maximum reverse channel threshold and the minimum received $^{Eb}/_{Io}$ for any mobile radio is less than or equal to the reverse channel minimum, the base station instructs the mobile radios to increase power.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a flowchart of the process of the present invention.

FIG. 2 shows a graph of the frame error rate versus $^{Eb}/_{Io}$.

FIGS. 3*a* and 3*b* show a typical forward packet channel structure in accordance with the present invention.

FIG. 4 shows the power control bit positions in accordance with the present invention.

FIG. 5 shows a block diagram of a typical mobile radio in accordance with the present invention.

FIG. 6 shows a block diagram of a typical base station in accordance with the present invention.

FIG. 7 shows the format of a forward CDMA channel in accordance with the present invention.

FIG. 8 shows the format of a reverse CDMA channel in accordance with the present invention.

FIG. 9 shows a plot of the transmit power of two radios and their reaction to power control commands in accordance with the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

The present invention encompasses a pair of channels, subsequently referred to as the forward and reverse packet channels. The base station communicates with the mobile radios over the forward channel and the mobile radios communicate with the base station over the reverse channel. A base station uses the power control process of the present invention, over the forward packet channel, to dynamically adjust the transmit power of one or more mobile radios transmitting on the reverse packet channel.

The following discussion refers to mobile radios and base stations as the preferred embodiment. Mobile radios include radiotelephones used in both a terrestrially based communication system and a satellite based communication system. Similarly, the base stations can be located on the earth or as orbiting satellites.

The reverse packet channel, in the preferred embodiment, is a variable rate channel that transmits data packets that have been broken up into a sequence of one or more frames. In an alternate embodiment, the reverse packet channel handles data at a fixed rate.

Each transmission includes a preamble, to aid in spread spectrum acquisition, followed by the datagram. The preamble of the reverse packet channel is the same as the preamble used in the access channel; a sequence of one or more unmodulated frames of Walsh function **0**. The access channel preamble is discussed in greater detail in TIA/EIA IS-95. Alternate embodiments use other preambles than the Walsh function **0**. Another alternate embodiment includes frames modulated by known frequencies. However, this increases receiver complexity.

In the preferred embodiment, the forward CDMA channel consists of a pilot channel, a synchronization channel, one or more paging channels, one or more forward packet channels and forward traffic channels. FIG. 7 illustrates the format of the preferred embodiment of the forward CDMA channel including the traffic channels (**705**) and packet channels (**710**) with power control subchannels (**715**). The forward packet channel is a spread spectrum channel similar in operation to the forward traffic channel as disclosed in IS-95 as is illustrated in FIGS. **3***a* and **3***b*. A more complete discussion of this channel can be found in IS-95.

FIG. **8** illustrates the format of the reverse CDMA channel. A set of one or more access channels (**805**) are associated with each paging channel. An overhead message defines the number of access channels (**805**) that are associated with a particular paging channel. Similarly, one or more reverse packet channels are associated with a forward packet channel and an overhead message defines the number of reverse packet channels associated with a particular forward packet channel. Different reverse packet channels (**810**) associated with the same forward packet channel are differentiated by each reverse packet channel having a unique spreading code.

In the preferred embodiment, assignment of a reverse packet channel to a forward packet channel is static in that a mobile radio continually monitors the same forward packet channel while in the same cell. The channel may be assigned by using information from overhead parameters, by assignment on a per mobile radio basis, or via some static procedure.

The reverse packet channels enable multiple mobile radios to transmit simultaneously. In the preferred embodiment of a CDMA system, the multiple transmissions from multiple mobile radios only collide if their multipath components overlap as was described previously. In the preferred embodiment, a mobile radio randomly chooses, for its transmissions, one of the reverse packet channels associated with a forward packet channel. Alternate embodiments use other methods for choosing channels. Additionally, the transmission time of a radio using a reverse packet channel can be randomized as is done for the access channel. These techniques lower the probability of a collision by distributing the mobile radios over channels or time. This also serves to increase system capacity. When the mobile radio retransmits a packet, it may randomize transmission time and choice of reverse packet channel so as to avoid collisions as previously described for the access channel.

A flowchart of the power control process of the present invention is illustrated in FIG. **1**. In the preferred embodiment, this process uses the dimensionless ratio E_b/I_o to determine whether to adjust the radio's transmit power and, if so, whether to increase or decrease the power. Alternate embodiments use other signal quality metrics for threshold comparison such as P_r/N_o, P_r, or some scaled equivalent of E_b/I_o; P_r being the received power.

The E_b/I_o ratio is a standard quality measurement for digital communications system performance. The ratio expresses the energy per bit to the total interference spectral density of the channel. E_b/I_o can be considered a metric that characterizes the performance of one communication system over another; the smaller the required E_b/I_o the more efficient is the system modulation and detection process for a given probability of error. A more detailed discussion of this concept can be seen in B. Sklar, *Digital Communications, Fundamentals and Applications*, Chapter 3 (1988).

The process of the present invention, in the preferred embodiment, is used in a typical CDMA cellular radiotelephone system as disclosed in the '459 patent described above. The radiotelephone system is comprised of numerous radiotelephones that transmit to a base station over a reverse channel and receive from the base station over a forward channel.

The maximum total E_b/I_o is subsequently referred to as the allocated E_b/I_o (step **100**). The allocated E_b/I_o may vary with the traffic channel load.

The allocated E_b/I_o is used by the base station as the maximum threshold for all mobile radios transmitting to that base station. If a particular mobile radio transmitting to the base station requires a transmit power increase, the base station will not instruct the mobile radio to increase its transmit power beyond the allocated E_b/I_o.

In the preferred embodiment, the reverse link has a desired E_b/I_o assigned to it by the base station (step **105**). The desired ratio is the value that gives a high probability that a data packet will be received without error from the base station and yet maintains a high capacity as explained above. As an example, a packet consisting of 10 frames with a 3 dB E_b/I_o has an approximate error rate of 10%, as seen in FIG. **2**.

Choosing a larger E_b/I_o causes the packet error probability of the transmission to decrease. This is illustrated in the graph of FIG. 2. This plot shows the effect to the frame error rate of increasing E_b/I_o. For example, referring to FIG. **2**, if the E_b/I_o is 4 dB, the resulting error rate for the 10 frame packet is 4×10^{-3}. If E_b/I_o is chosen too large, however, the transmitted signal may cause interference to other mobile radios communicating with the base station.

The received E_b/I_o of each mobile radio is estimated by the base station (step **115**). Since the base station acquires the mobile radios during the transmission of the packet preamble, it can determine the number of mobile radios that are transmitting to the base station. These individual E_b/I_o's for the base station are summed (step **120**) and, as will be discussed later, the sum is used in determining the proper power control command to be sent to the mobile radios.

In the preferred embodiment, all mobile radios that are listening to the same forward packet channel are also receiving the same power control bit stream. Thus each power control bit stream controls all the mobile radios that are transmitting on any of the reverse packet channels that are associated with the forward packet channel.

The base station controls the mobile radio's transmit power using closed loop power control. In other words, if the base station determines that the transmit power of the received signal is too high, the base station sends a command to the mobile radio to decrease its transmit power. The base station sends a command instructing an increase if the

transmit power is too low. This power control command, in the preferred embodiment, is two modulation symbols. The preferred embodiment format of such a word is illustrated in FIG. 4.

In the preferred embodiment, the power control bit of the present invention is set by the base station according to the following conditions. The power control bit is set to a 1, instructing the mobile radio to decrease its power output if the following condition is true:

$$\left(\sum_i (E_b/I_o)_i \geqq \text{allocated } E_b/I_o\right)$$

OR

$$\left(\left(\min_i (E_b/I_o)_i\right) > \text{desired } E_b/I_o\right)$$

where i=the i^{th} mobile radio.

The power control bit is set to a 0, instructing the mobile radio to increase its power output if the following condition is true:

$$\left(\sum_i (E_b/I_o)_i < \text{allocated } E_b/I_o\right)$$

AND

$$\left(\left(\min_i (E_b/I_o)_i\right) \leqq \text{desired } E_b/I_o\right)$$

where i=the i^{th} mobile radio.

In other words, the first condition (step **125**) is true when the total or sum of the E_b/I_o's of all the mobile radios communicating with the base station is greater than or equal to the maximum E_b/I_o or when the minimum E_b/I_o of any one of the mobile radios is greater than the desired E_b/I_o. In this case, the total amount of E_b/I_o that has been allocated to the reverse packet channel has been exceeded as might be the case when too many mobile radios are transmitting. A particular mobile radio's E_b/I_o could also have been higher than needed and the received signal may perturb the remaining reverse packet channel users so the mobile radio's power output needs to be decreased (step **130**).

The second condition (step **135**) is true when the sum of the E_b/I_o's of all the mobile radios communicating with the base station is less than the maximum E_b/I_o and when the minimum E_b/I_o of any one of the mobile radios is less than or equal to the desired E_b/I_o. In both cases, the mobile radio's E_b/I_o is too low and the received signal may not be demodulated correctly so the mobile radio's power output needs to be increased (step **140**).

Alternate embodiments of the power control process of the present invention uses other conditions yielding similar results. Also, the other comparison thresholds mentioned above could be substituted in the above conditions to yield similar results.

In an alternate embodiment of the power control process of the present invention, the base station determines if the command to increase power will cause the mobile radio's power output to exceed the allocated E_b/I_o. If this is true, the base station commands the mobile radio to decrease its transmit power instead of increasing.

If there is a single transmission on the reverse packet channel of the present invention, power control is performed on the traffic channel as discussed in U.S. Pat. No. 5,056,109 to Gilhousen et al. and assigned to Qualcomm, Inc. When there are multiple transmissions, the base station tries to keep the mobile radio with the poorer E_b/I_o at the allocated E_b/I_o, subject to the constraint that the total received E_b/I_o is not too great.

An example of the above described power control process is illustrated in FIG. 9. FIG. 9 shows a plot of the transmit power of two users, A and B. The desired E_b/I_o is the lower threshold while the upper threshold is the allocated E_b/I_o. The upper curve shows $\Sigma E_b/I_o$ that, in this case, is A+B. The power control commands transmitted by the base station are illustrated at the bottom of the plot.

The initial portions of the user A and user B waveforms are both above the desired E_b/I_o and the $\Sigma E_b/I_o$ is above the allocated E_b/I_o. Using the process of the present invention, the base station sends out power control commands instructing the mobiles to turn down their transmit power. As required by IS-95 7.1.3.1.7, a two power control group delay issued before a power control command is implemented. Therefore, the plot shows that the power does not decrease until the slot i+2. This is illustrated in FIG. 4.

After four decrease power control commands, the user B transmit power is below the desired E_b/I_o. The base station then sends three turn up commands. After the two power control group delay, the output power of user B is above the desired E_b/I_o and the $\Sigma E_b/I_o$ is above the allocated E_b/I_o. This process continues in a similar manner.

If a large number of transmissions are received on a busy channel, the power control process of the present invention limits the power output at the allocated E_b/I_o. This will likely force a higher error rate in some packet transmissions. In this case, the base station can make the decision to power control only a few streams by making the minimum E_b/I_o in the above conditions over a subset of the received transmissions. This will likely limit the impact on other mobile radios.

In the preferred embodiment, the desired E_b/I_o can be adjusted for different channel conditions so as to maintain a desired packet error rate. If the packet error rate is too high for a desired E_b/I_o, the base station can increase the desired E_b/I_o, thus lowering the packet error rate. Alternatively, if the packet error rate is lower than needed, the base station can decrease the desired E_b/I_o, thus increasing the packet error rate.

This latter adjustment serves to increase the overall system capacity. The adjustments mentioned above may need to be done for different channel conditions. For example, if there are many multipath components, the base station may not be able to combine energy as effectively. In the art, this is called combining loss. On the other extreme, fading may cause a higher packet error rate if there is only one multipath component. To maintain a low packet error rate in both these cases, the base station may increase the desired E_b/I_o.

In the preferred embodiment, the desired E_b/I_o is the same for all mobile radios. Alternatively, the desired E_b/I_o could be different for each mobile radio. The previous equations can then be written as:

$$\left(\sum_i (E_b/I_o)_i \geqq \text{allocated } E_b/I_o\right)$$

OR

$$(\forall i|((E_b/I_o)_i > \text{desired}(E_b/I_o))_i)$$

where i=the i^{th} mobile radio and $\forall i|$ signifies that for all i, such that if the above is true, the mobile radio is told to decrease its power; and

$$\left(\sum_i (E_b/I_o)_i < \text{allocated } E_b/I_o\right)$$

AND

-continued

$$(\exists i | (E_b/I_o)_i \leqq \text{desired } (E_b/I_o)_i)$$

where i=the i^{th} mobile radio and ∃i| signifies that there exists an i such that if the above is true, the mobile radio is told to increase its power.

After transmitting the first access probe at a minimum power level, the mobile radio increases the power of successive probes within each access probe sequence by a predetermined step amount. This step amount is different for different embodiments and is set to optimize the system performance.

A simplified block diagram of a typical mobile radio is illustrated in FIG. 5. Signals received from the base station are received with the antenna (**501**). The duplexer (**502**) splits the signal to the low noise amplifier (**503**) that amplifies the signal. This amplified signal is then input to a variable gain amplifier (**504**), the gain of which is controlled by a receive automatic gain control circuit (**505**). The output of the variable gain amplifier (**504**) is input to a demodulator and decoder (**506**). The demodulator portion removes the signal modulation so that the packetized information can be broken up by the packet receiver (**507**) into a digital form that is usable by a computer or other electronic device.

A digital signal to be transmitted from a computer or other electronic device is first packetized (**520**). The packets of data are then modulated by the encoder and modulator (**525**). The modulated signal is input to a variable gain amplifier (**530**) that amplifies the signal prior to the fixed gain power amplifier (**535**). The output of the power amplifier (**535**) is input to the duplexer (**502**) that couples the signal to the antenna (**501**) to be radiated.

The gain of the variable gain amplifier is controlled by the power control bit of the present invention that is transmitted by the base station. When the mobile radio receives the power control bit, it is input to the closed loop power control circuitry (**540**). This circuitry (**540**) simply determines whether the power control bit is a logic 1 or a logic 0 and generates the proper control voltage to increase or decrease the gain of the variable gain power amplifier (**530**).

In the preferred embodiment, the gain is increased or decreased in 1 dB increments. The power control circuitry (**540**) outputs a digital value indicative of each 1 dB increase or decrease. This digital value is input to a digital to analog converter (DAC) (**545**). The DAC converts the digital value to an analog signal that controls the gain of the variable gain power amplifier. In this way, the process of the present invention enables the base station to dynamically adjust the transmit power of the mobile radio as conditions change.

Alternatively, the increase and decrease in gain does not have to be by the same amount. In addition, the increase and decrease in power control gain may adapt based upon the sequence of up or down commands that have been received by the mobile radio.

FIG. **6** shows a block diagram of a typical CDMA base station system incorporating the power control process of the present invention. This diagram shows the antennas of a base station (**601 and 602**) that receive the signals transmitted from the mobile radio. The received signals are distributed to various receivers (**605–620**) depending on which one is being used. The receivers (**605–620**) generate the demodulated bits for use by other devices such as external computers.

The receivers (**605–620**) also generate the signal to interference ratios, $^{Eb}/_{Io}$, that are used by the power control process of the present invention (**625**) to generate the power control bits. These bits are inserted into the power control stream by puncturing (**630**) the forward channel signal that has been generated by the modulator (**635**). This signal is then eventually transmitted by the transmit antenna (**603**) to the mobile radio.

In the preferred embodiment, the power control is performed by a single bit. Alternate embodiments, however, use multiple bits to form a power control command word. Such a word can not only control the direction of the transmit power but the rate of power change. For example, one bit of the command instructs the radio to increase power while another bit of the command instructs the increase to be in 2 dB increments instead of 1 dB.

In summary, the power control process of the present invention uses a single power control bit stream from the base station to control the transmit power of multiple radios. The signal quality metric, $^{Eb}/_{Io}$, is used to determine whether to increase or decrease the power and what amount of power change is needed.

I claim:

1. A method for controlling transmit power of a plurality of radios, the plurality of radios communicating with a base station, the method comprising the steps of:

the base station determining the transmit power required from each radio of the plurality of radios;

the base station instructing more than one of the plurality of radios to monitor a single power control bit stream; and

the base station transmitting said single power control bit stream to the more than one of the plurality of radios to instruct each of the more than one of the plurality of radios to alter its transmit power in response to the required transmit power.

2. The method of claim **1** wherein the step of determining the transmit power comprises the steps of:

determining a first signal quality threshold;

determining a second signal quality threshold;

determining a signal quality metric for each radio of the plurality of radios; and

comparing the signal quality metrics for the plurality of radios to the first and second signal quality thresholds.

3. The method of claim **2** wherein the signal quality metric is an energy per bit to total interference spectral density ratio.

4. The method of claim **2** and further including the steps of:

increasing the transmit power of a radio having a signal quality metric that is less than the first signal quality threshold; and

decreasing the transmit power of a radio having a signal quality metric that is greater than the second signal quality threshold.

5. The method of claim **2** wherein the first signal quality threshold is a minimum signal quality threshold and the second signal quality threshold is a maximum signal quality threshold.

6. A method for controlling a power output of a remote transmitter in a first mobile radio of a plurality of mobile radios, the first mobile radio receiving signals from a base station over a forward channel wherein said forward channel includes a first slot assigned to at least said first mobile radio and a second slot assigned to at least one other of said plurality of mobile radios, the base station receiving signals from the first mobile radio over a reverse channel, the method comprising the steps of:

determining a maximum reverse channel signal quality metric;

determining a desired reverse channel signal quality metric;

determining a reverse channel signal quality metric for each of the plurality of mobile radios, thus creating a plurality of reverse channel signal quality metrics;

determining a minimum reverse channel signal quality metric of the plurality of mobile radios;

summing the plurality of reverse channel signal quality metrics; and

the base station instructing the first mobile radio to monitor transmission of power control information in said first slot, said power control information instructing the remote transmitter to decrease the power output if the sum of the reverse channel signal quality metrics is greater than or equal to the maximum reverse channel signal quality metric or the minimum reverse channel signal quality metric is greater than the desired reverse channel signal quality metric.

7. The method of claim 6 and further including the step of the base station adjusting a minimum reverse channel energy per bit to total interference spectral density ratio depending on reverse channel conditions.

8. The method of claim 6 and further including the step of adjusting a maximum reverse channel energy per bit to total interference spectral density ratio in response to an increase or decrease in the quantity of said plurality of mobile radios.

9. The method of claim 6 wherein the mobile radio is a code division multiple access radiotelephone and the base station is a code division multiple access base station.

10. The method of claim 6 wherein the signal quality metric is an energy per bit to total interference spectral density ratio.

11. The method of claim 10 wherein the energy per bit to total interference spectral density ratio is $^{Eb}/_{Io}$.

12. A method for controlling a power output of a remote transmitter in a first mobile radio of a plurality of mobile radios, the first mobile radio receiving signals from a base station over a forward channel, the base station receiving signals from the first mobile radio over a reverse channel, the method comprising the steps of:

determining a maximum reverse channel signal quality metric;

determining a desired reverse channel signal quality metric;

determining a reverse channel signal quality metric for each of the plurality of mobile radios, thus creating a plurality of reverse channel signal quality metrics;

determining a minimum reverse channel signal quality metric of the plurality of mobile radios;

summing the plurality of reverse channel signal quality metrics; and

the base station instructing the remote transmitter to monitor power control information associated with a predefined slot of said forward channel, said power control information instructing the remote transmitter to increase the power output if the sum of the reverse signal quality metrics is less than the maximum reverse channel signal quality metric.

13. The method of claim 12 and further including the step of the base station adjusting a minimum reverse channel energy per bit to total interference spectral density ratio depending on reverse channel conditions.

14. The method of claim 12 and further including the step of adjusting a maximum reverse channel energy per bit to total interference spectral density ratio in response to an increase or decrease in the quantity of the plurality of radiotelephones.

15. A method for controlling a power output of a remote transmitter in a first mobile radio of a plurality of mobile radios, the first mobile radio receiving signals from a base station over a forward channel, the base station receiving signals from the first mobile radio over a reverse channel, the method comprising the steps of:

determining a maximum reverse channel energy per bit to total interference spectral density ratio;

determining a desired reverse channel energy per bit to total interference spectral density ratio;

determining a reverse channel energy per bit to total interference spectral density ratio for each of the plurality of mobile radios, thus creating a plurality of reverse channel energy per bit to total interference spectral density ratios;

determining a minimum reverse channel energy per bit to total interference spectral density ratio of the plurality of mobile radios;

summing the plurality of reverse channel energy per bit to total interference spectral density ratios; and

the base station instructing the remote transmitter to monitor power control information associated with a predefined slot of said forward channel, said power control information instructing the remote transmitter to increase the power output if the minimum reverse energy per bit to total interference spectral density ratio is less than or equal to the desired reverse channel energy per bit to total interference spectral density ratio.

16. A method for controlling power output of a first remote transmitter of a plurality of remote transmitters, each remote transmitter being part of a mobile radiotelephone, the plurality of mobile radiotelephones receiving data packets from a cellular base station over a forward channel, the cellular base station receiving data packets from the plurality of mobile radiotelephones over a reverse channel, the reverse channel having a maximum energy per bit to total interference spectral density ratio, the data packets being comprised of frames, the method comprising the steps of:

determining a desired reverse channel energy per bit to total interference spectral density ratio;

determining a energy per bit to total interference spectral density ratio on the reverse channel for each of the remote transmitters, thereby creating a plurality of energy per bit to total interference spectral density ratios;

summing the plurality of energy per bit to total interference spectral density ratios to produce a summation value;

determining a minimum reverse channel energy per bit to total interference spectral density ratio for the plurality of mobile radiotelephones;

comparing the maximum reverse channel energy per bit to total interference spectral density ratio to the summation value;

comparing the minimum reverse channel energy per bit to total interference spectral density ratio to the desired energy per bit to total interference spectral density ratio; and

the base station instructing the first remote transmitter to decrease power if the summation value is greater than or equal to the maximum reverse channel energy per bit to total interference spectral density ratio or the mini-

mum reverse channel energy per bit to total interference spectral density ratio is greater than the desired reverse channel energy per bit to total interference spectral density ratio.

17. The method of claim 16 wherein each of the energy per bit to total interference spectral density ratios is determined by an $^{Eb}/_{Io}$ of the reverse channel.

18. The method of claim 16 wherein each of the energy per bit to total interference spectral density ratios is determined by a $^{Pr}/_{No}$ of the reverse channel.

19. The method of claim 16 wherein each of the energy per bit to total interference spectral density ratios is determined by a scaled version of an $^{Eb}/_{Io}$ of the reverse channel.

20. A method for controlling power output of a first remote transmitter of a plurality of remote transmitters, each remote transmitter being part of a mobile radiotelephone, the plurality of mobile radiotelephones receiving data packets from a cellular base station over a forward channel, the cellular base station receiving data packets from the plurality of mobile radiotelephones over a reverse channel, the reverse channel having a maximum energy per bit to total interference spectral density ratio, the data packets being comprised of frames, the method comprising the steps of:

determining a desired reverse channel energy per bit to total interference spectral density ratio;

determining a energy per bit to total interference spectral density ratio on the reverse channel for each of the remote transmitters, thereby creating a plurality of energy per bit to total interference spectral density ratios;

summing the plurality of energy per bit to total interference spectral density ratios to produce a summation value;

determining a minimum reverse channel energy per bit to total interference spectral density ratio for the plurality of mobile radiotelephones;

comparing the maximum reverse channel energy per bit to total interference spectral density ratio to the summation value;

comparing the minimum reverse channel energy per bit to total interference spectral density ratio to the desired energy per bit to total interference spectral density ratio; and

the base station instructing the first remote transmitter to increase power if the summation value is less than the maximum reverse channel energy per bit to total interference spectral density ratio and the minimum reverse channel energy per bit to total interference spectral density ratio is less than or equal to the desired reverse channel energy per bit to total interference spectral density ratio.

21. The method of claim 20 and further including the step of the base station adjusting the minimum reverse channel energy per bit to total interference spectral density ratio depending on reverse channel conditions.

22. The method of claim 20 and further including the step of adjusting the maximum reverse channel energy per bit to total interference spectral density ratio in response to an increase or decrease in the quantity of the plurality of radiotelephones.

23. A method for controlling transmit power of a plurality of radios, the plurality of radios communicating with a base station, the method comprising the steps of:

the base station determining the transmit power required from each radio of the plurality of radios;

the base station transmitting a power control message multiplexed into a series of power control slots, each of said power control slots including power control information instructing each radio within an associated subset of said plurality of radios to alter its transmit power;

the base station instructing each radio within the same said associated subset to monitor said power control information in a same one of said power control slots.

24. A method for controlling transmit power of a plurality of radios using a power control message provided by a base station, the method comprising the steps of:

receiving, at more than one of said plurality of radios, instructions to monitor the same selected portion of said power control message; and

receiving, at said more than one of said plurality of radios, power control information within said same selected portion of said power control message, said power control information instructing each of said more than one of said plurality of radios to alter its transmit power in response to a required transmit power.

25. A method for controlling transmit power of a plurality of radios using a power control message provided by a base station, the method comprising the steps of:

transmitting, from said base station, instructions indicating that a subset said radios monitor the same selected portion of said power control message; and

transmitting, from said base station, power control information within said same selected portion of said power control message, said power control information indicating that transmission power of each of said more than one of said plurality of radios should be altered in response to a required transmit power.

26. A method for controlling transmit power of a plurality of radios, the plurality of radios communicating with a base station, the method comprising the steps of:

the base station determining the transmit power required from each radio of the plurality of radios;

the base station instructing a first subset of said plurality of radios to monitor a first power control bit stream, and a second subset of said plurality of radios to monitor a second power control bit stream; and

the base station transmitting said first and said second power control bit streams to instruct each of the plurality of radios in the first and second subsets of said plurality of radios to alter its transmit power in response to the required transmit power.

27. A method for controlling transmit power of a plurality of radios, the plurality of radios communicating with a base station, the method comprising the steps of:

the base station determining the transmit power required over a reverse channel from each radio of the plurality of radios; and

the base station transmitting a single power control bit stream to the more than one of said plurality of radios to instruct each of the more than one of said plurality of radios to alter its transmit power in response to the required transmit power and in response to a maximum total reverse channel signal quality metric;

wherein said maximum total reverse channel signal quality metric is set based upon a sum of reverse channel signal quality metrics associated with said plurality of radios.

28. A method for controlling a power output of a remote transmitter in a first mobile radio of a plurality of mobile radios, the first mobile radio receiving signals from a base station over a forward channel, the base station receiving

signals from the first mobile radio over a reverse channel, the method comprising the steps of:

determining a reverse channel signal quality metric for each of the plurality of mobile radios, thus creating a plurality of reverse channel signal quality metrics;

summing the plurality of reverse channel signal quality metrics; and

the base station instructing the remote transmitter to decrease the power output at least if the sum of the reverse channel signal quality metrics is greater than or equal to a maximum reverse channel signal to noise ratio.

29. The method of claim 28 further including the steps of:

determining a minimum reverse channel signal quality metric of the first mobile radio; and

the base station instructing the remote transmitter to decrease the power output if the minimum reverse channel signal quality metric is greater than a desired reverse channel signal quality metric.

* * * * *